polysun®
SIMULATION
SOFTWARE

User Manual

vela solaris

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1 Introduction to Polysun

Polysun is a software that enables users to effectively simulate solar-thermal, photovoltaic and geothermal systems. This manual provides users with extensive operating instructions that will allow them to profitably take advantage of the wide range of functions provided by Polysun. In the following pages of this handbook you will find detailed descriptions of the single components as well as comprehensive information on the models on which they are based. Technical issues on the use of Polysun are dealt with in greater detail in a separate document (this can be obtained directly from the software by pressing the F1 button).

Tip: for quick user reference most functions, buttons, etc have been fitted with exhaustive tool-tips. Simply place and rest the pointer on the required item to view a short description of the relevant item.

2 Basic Structure of Polysun

2.1 Management of projects, templates and variants

In Polysun the **project** defines the indications on the location and on the consumers of the solar energy system. It also contains diverse variants. The project can be started from the menu *Project – New project* or by means of the *Project Wizard*. You can save a project with the function *Project – Save project*.

The **variant** defines all of the components and connections of the solar energy system. A variant can be created in the *Variant – Create new variant* menu (at the Designer level), by means of the *Variant Wizard* or, if a template is visualized, with *Add template to project*. It is possible to simulate each variant individually and to visualize the results. The variant is always included in a project and can be only saved together with it. Normally different variants are considered in order to make comparison and optimize the project.

Polysun makes available a series of pre-defined **templates**. The template defines (as the variant) a solar energy system. The templates can be inserted into the project, and they are then indicated as variants and can therefore be modified or simulated.

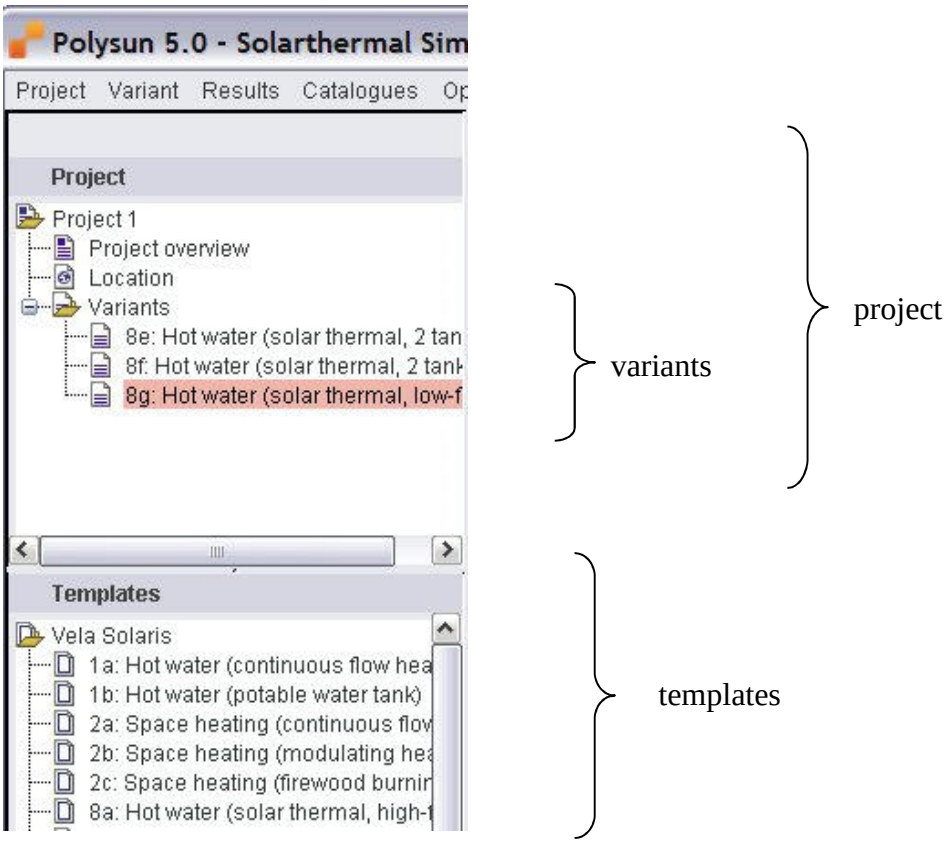


Figure 1: folder-tree with project and templates

2.2 Reference variants

Polysun allows the use of reference variants for the analysis and enhancement of solar energy

systems. To this end a variant may be specially labeled within the project-tree (right mouse click – „Variant as reference...“).

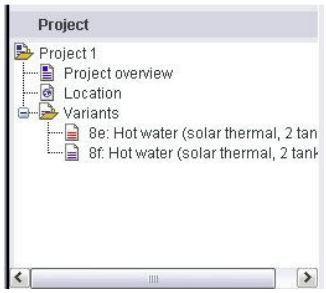


Figure 2: project-tree with reference variant

Important values like, eg. *Solar savings* (Fractional solar savings, F_{SS}) may only be calculated with the aid of the definition of a reference system. Solar savings are defined as follows:

$$F_{ss} = 1 - \frac{(E_{aux} - E_{par})_{sol}}{(E_{aux} - E_{par})_{ref}}$$

where E_{aux} refers to the Auxiliary energy and E_{par} refers to the Parasitic energy of the respective system („sol“ = solar energy system, „ref“ = reference system)

Example: In a solar energy system variants with and without solar input are required to be compared. To this end a model is applied as a variant in the project. Copy the variant (right mouse click – „Copy variant...“) and alter it so that the pump in the solar loop is not running. This variant will then be set as a reference (right mouse click – „Variant as reference...“). Once the simulation results from both variants are available the solar savings FSS will be shown in the results.

Discussion: For customer service purposes and more in particular in a retrofitting situation the existing heating system too may be recreated in detail and set as a reference. This will enable to figure out the expected solar savings with a new solar energy system.

Tip: In the *Options – Settings – Simulation* menu you will be able to select when Polysun should calculate the reference system:

- „Simulate reference upon confirmation“: the user should confirm the start of the reference simulation
- „Simulate reference without confirmation“: the reference simulation will be restarted immediately after the simulation of a variant
- „ Do not simulate reference“: the reference simulation will not be automatically simulated and the user must start the simulation manually

2.3 User levels

The variants can be more or less modified according to the user level and version. The user of Polysun Light can utilize the already existing templates and modify the components by means of data present in the catalogue. The level of Polysun Professional is distinguished by the fact that the user can create his own catalogue entries. The most advanced level is Polysun Designer, which allows the creation of new hydraulic schemes.

Acquiring *Polysun solarthermal simulation, heatpump simulation* or *photovoltaic simulation* your software will be automatically updated with all the features and functions included in the respective user levels. These modules provide enhanced design freedom in the creation of your individual systems. The full-version combines all the above modules enabling users to take full advantage of all features made available by Polysun. This will enable users to design their very own systems drawing on all available components or defining their own components.

3 General Notions: Solar Energy

The use of solar energy comprises a wide range of uses. First of all there is the conversion of energy from solar rays into thermal (heat) energy. This thermal energy can be used for many different purposes: for the production of electrical energy (by means of thermoelectric solar power stations), as process heat for industrial use, for the generation of cold (for example by means of absorption cooling) or for domestic use. The Polysun simulation program is concerned primarily with domestic use, therefore the production of heat for hot water and space heating.

Polysun makes it also possible to graphically represent photovoltaic systems enabling sunlight to be directly converted into electrical power. This effective solar energy exploitation technology will be dealt with in greater detail in a separate section of this handbook.

To collect the most possible energy coming from solar rays, collectors are oriented at an optimum angle with respect to the sun. Solar radiation is converted into heat by means of a highly absorbant layer (absorber) inside of the collector. A glass covering prevents the thermal energy from being dispersed into the environment. The absorber is passed through by a liquid, which transmits the heat directly to the user, or to a tank.

From the periods of sunshine which rarely coincides with those of hot water consumption, thermal energy is “temporarily stored” in a tank. The thermal tank used is possibly sized in a way that allows the satisfaction of hot water demand (energy demand) of 2-4 days. In this way it is possible to easily make it through even less sunny summer periods. In the winter season it is necessary in many cases to employ additional energy sources, such as oil, gas, or wood. If a system is well designed, it allows for proper functioning with the least possible use of additional energy.

3.1 Efficiency and orientation of the collector

The success of a solar energy system depends on the availability of solar light. In line with the principle, northern countries are just as suitable as those in the south meridian for the use of solar energy systems, from the time that throughout the course of the year, every point on the Earth is exposed to the sun for the same amount of time. The differences are due to the diverse meteorological conditions, to the inclination of solar rays and to the thickness of the atmospheric layer that the light has to pass through. This thickness increases when we move away from the equator blocking in this manner the intensity of solar light.

To compare solar radiation at different points of the Earth, let’s consider a panel firmly mounted and facing south. This should be inclined in a way that during the year the total radiation (global radiation) is at the maximum. The irradiated energy is composed of direct radiation and diffuse radiation. The diffuse radiation consists of a good part of the light propogated by the clouds. The irradiation values vary according to location as follows:

Location	Latitude	Optimum tilt angle	Gdirect [kWh/m2]	Gdiffuse [kWh/m2]	Global radiation [kWh/m2]
Oslo	59.5°	44°	647	568	1232
Berlin	52.3°	37°	560	576	1148
Rapperswil	47.1°	33°	537	682	1219
Davos	46.5°	44°	1000	748	1749
Rome	42.1°	35°	1054	740	1802
Cairo	30.1°	28°	1483	756	2245
Nairobi	-1.2°	7°	1024	915	1940

The location with the highest annual irradation differs from that with the lowest only by a factor of two. Davos in fact reaches almost 80% of the irradiation of Cairo. The optimum tilt angle of the collector corresponds to the latitude, or even a little lower (to be able to capture a greater quantity of diffuse radiation). But it goes considered that, with a greater tilt angle of the collector, the low winter solar rays can be captured better, increasing this way efficiency during winter which is important, above all for space heating. If there are no objects causing shade in the area surrounding the solar energy system, the ideal orientation is always towards South (and in the southern hemisphere always towards North, as in the case of Nairobi). Things change when trees or houses cover the eastern or western parts of the sky.

The percentage of diffuse light is also considerable. In Cairo it corresponds to about a third. In Rapperswil to more than half. This explains why the solar collectors continue to produce hot water even if the sky is covered. Only in the presence of less than 10% of the maximum solar radiation (of about 1000 W/m^2), does the activity of the collector become useless.

3.2 The path of the sun in the period of a day/year

The path of the sun from east to west takes place on an orbit (ecliptic) which here, at the beginning of spring and autumn, has an angle of 42.9° (= 90° - 47.1°) in respect to the horizontal plane. In correspondence to these two days the path of the sun begins exactly in the East and ends exactly in the West. In summer the ecliptic goes up to 66.4°(= 42.9°+ 23.5°). The beginning of the solar orbit takes place in the North-East and finishes in the North-West. This means that a collector oriented towards South is irradiated on its back side, which does not favour the production of energy. This also is a part of the energy which in the annual balance becomes lost in the northern regions. During winter the ecliptic is only equal to 19.4° (= 42.9° - 23.5°) and the path of the sun goes from South-East to South-West.

3.3 Horizon

To make a reliable calculation regarding the energy yield of a solar energy system, any possible shadow creating objects, such as adjacent houses, trees, mountains etc. are taken into consideration. In the project folder you can insert the horizon for the location of the system:

As an additional feature the horizon line can also be imported. To do this you will need to call-up from the project folder tree the dialogue box containing the relevant location list. Here horizon information can be entered in .hor format by simply pressing the ”Import“ button. Files in this format are made available by external tools such as:

Tool	Supplier
horicatcher	www.meteotest.ch
Suneye	www.solmetric.com
Horizon	www.energiebüro.ch

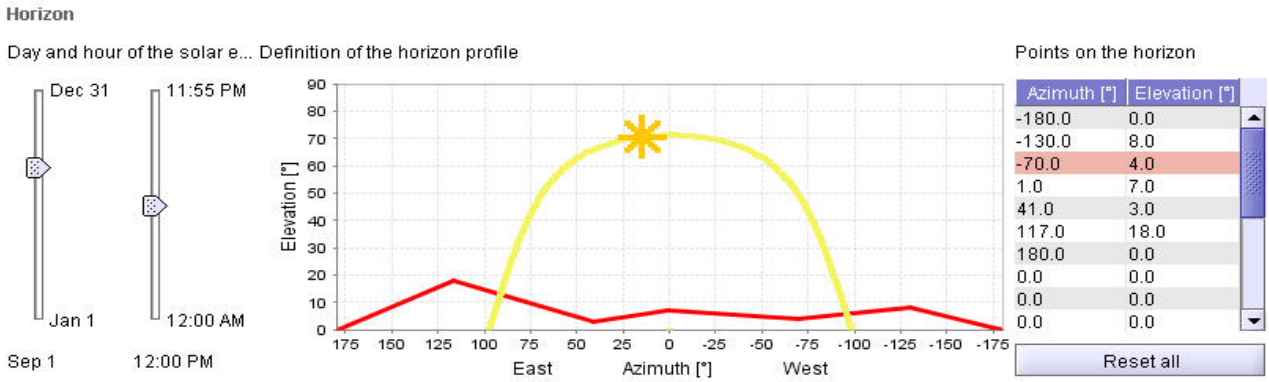


Figure 3: Horizon setting. The horizon line can easily be assessed visually; however, appropriate equipment makes it possible to determine the horizon line with greater accuracy. The collected data can later be entered in successive steps.

4 Photovoltaics

Contrary to solar-thermal energy photovoltaics enable sunlight to be directly converted into electrical power. The so-called "photovoltaic effect" is brought about by means of a variety of semi-conducting materials including silicon, gallium arsenide, cadmium telluride or copper indium diselenide. As soon as sunlight hits solar cells made from these materials electrons immediately stream from the negative to the positive pole causing a continuous current to be generated. The process is practically wear-free; no emissions or sounds are generated and no moving parts are involved in the process. The photovoltaic effect was discovered in 1839 by French physicist A.E. Becquerel.

A solar-cell has a typical voltage of 0.6 V and a maximum short-circuit current of over 3 A. As such a voltage is too low to run any appliance solar-cells are typically wired in series to form a solar module (typically 36 cells). As we speak extensive researches are conducted worldwide to develop new effective production processes and new types of solar-cells. Today the main trend in solar-cell-manufacture is towards Silicon solar-cells with the largest market-share being held by mono-crystalline solar-cells. A close second to these is the poly-crystalline technology followed by amorphous cells. New technologies such as CIS and CaTe-cells are also available on the market.

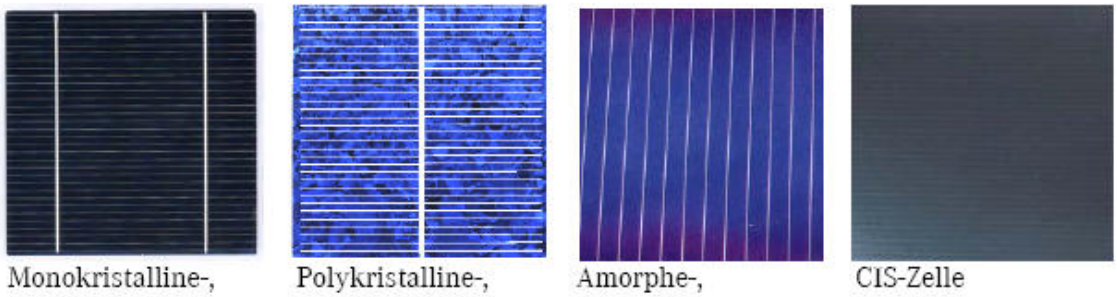


Figure 4: different types of solar-cells

A major factor for solar-cells is their efficiency; this refers to the ratio between the irradiance received by solar-cells and the amount of electrical power generated.

	Typical efficiency	Max. recorded efficiency	Max. in-lab recorded efficiency
Mono-crystalline	15-18%	22.7%	24%
Poly-cristallyne	13- 16%	18%	18.6%
Amorphous silicon	5- 7%	10.2%	12.7%
Cadmium telluride (CdTe)	7- 8.5%	13%	16%
Copper indium diselenide (CIS)	9- 11%	13%	18.8%

Table 1: Efficiency of different types of solar-cells

Solar-modules are typically defined in terms of their efficiency and their nominal power output at STC. The nominal power output at STC refers to the amount of electrical power a module is able to generate with an irradiance of 1000 W/m2, a module-temperature of 25°C and an AirMass of 1. Such conditions are seldom met in normal operation, if ever, only on sunny Spring days. For most of the year cells operate in substantially less favourable light and temperature conditions, i.e. a solar module's yield will be lower than the indicated STC value. Solar modules are wired in series

and in parallel; multiple modules wired in series are called a ”string“. In grid-connected systems the generated power is sent to an inverter that converts the collected direct current (DC) into alternating current (AC) and feeds it in the public power-supply system. Grid connection systems use a variety of inverters. If a central inverter, for example, is used all solar modules will be wired to the inverter by means of a terminal box. In string inverters the terminal box is replaced and each string is converted into alternating current.

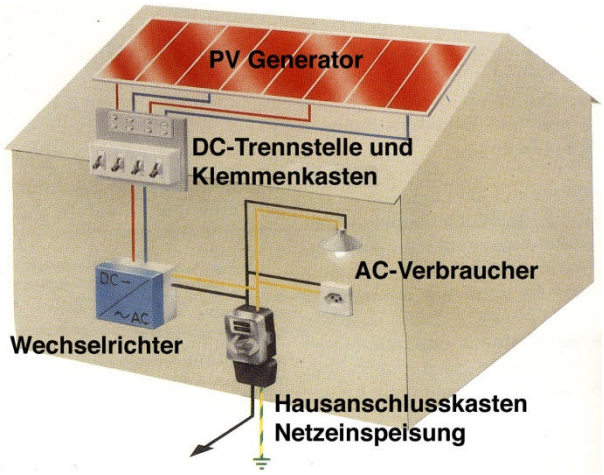


Figure 5: Functional chart of a grid-connected PV system (Source: Leitfaden Photovoltaische Anlagen; Deutsche Gesellschaft für Sonnenenergie, 2007)

A PV system with an installed power of 1 kWp (about 8m^2 solar module surface) placed on a south-facing roof on the Swiss Plateau is able to generate about 900 kWh electrical power a year. In the south of Switzerland and in more elevated locations (over 1000 metres a.s.l.) a higher solar irradiance results in substantially greater outputs. In a four year period a solar system is able to generate as much current as its was required to manufacture it. (Source: N. Jungbluth et. al.; Life Cycle Assessment of Photovoltaics; Update of the ecoinvent Database, 2007). Solar energy systems have a life-span in the range of 25 to 30 years, i.e. they can generate about 6 to 7 times the electrical power that was required to manufacture them. At the end of their life-span most components of solar-energy systems (solar-cells, glass, aluminum components).

Polysun’s PV module allows users to figure out the amount of electrical power their systems are likely to generate. An extensive database provides users with a wide variety of solar-modules and inverters they will be able to use to define their PV fields.

4.1 Definition of a PV field

Polysun makes it possible to set up PV fields having each an inverter and the desired number of series or parallel-wired modules. Each PV field has a specific orientation and tilt angle as well as a field-specific assembly system.
So that different orientations and pitches may be combined each variant enables multiple PV fields to be defined within it. Alternatively after a module has been chosen an assistant providing an overview of the suitable inverters may be called-up by simply pressing the *Wizzard* button.

4.2 Solar-module parameters

The definition of a solar-module requires, as a key parameter, that a suitable PV field is retrieved from the solar-module database or independently set-up as well as that an appropriate number of modules is determined. As an option the DC nominal power and the solar module surface may be entered based on which Polysun will automatically calculate the required number of modules. Additionally module orientation (South is 0°, East is +90°, West is -90°) and tilt angle (floor is 0°, façade is 90°) may also be defined.
Polysun also enables users to work out the yield of sun-tracking PV systems (single or two-axis solar trackers). We proceed on the assumption that the system is set-up to track the position of the sun (and not the clearest spot) and that the tracker is able to follow the entire course of the sun and not just a limited angle. For a graphical representation of this principle see chapter 5.4.6 Tracking.

4.3 Temperature effect and rear ventilation

The amount of energy generated by solar-modules depends both on irradiance and module temperature. Energy production increases approximately linearly with irradiance. The influence of temperature is smaller and is dependant on the type of cell-technology. A temperature increase of 10°C will cause, for example, the energy production of crystalline cells to be cut back by about 4 to 5%. Amorphous cells are practically immune to temperature swings.

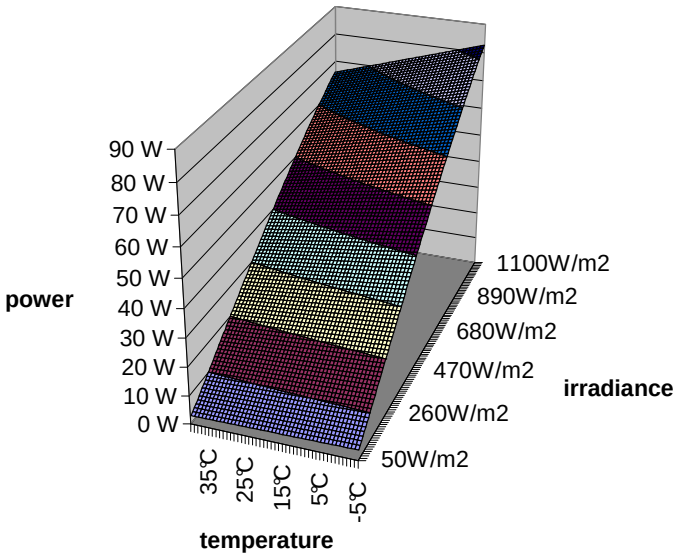


Figure 6: Influence of irradiance and temperature on a crystalline module (Source: R. Kröni et.al.; Final Report PV P+D, DIS 47456 / 87538 , February 2005; Energy Rating of Solar Modules)

In view of such temperature sensitivity an appropriate rear ventilation will result in a considerably higher yield. The software allows different types of ventilation to be set up as a parameter:

- Poor: for example a roof-integrated system with a very poor rear ventilation With an irradiance of 1000 W/m2 the module temperature will lie at about 40°C over the air temperature.
- Medium: for example a roof-mounted system with a rear ventilation of about 10 to 20cm. With an irradiance of 1000 W/m2 the module temperature will lie at about 30°C over the air temperature.
- Good: a free-standing system with a ground clearance in excess of 20cm. With an irradiance of 1000 W/m2 the module temperature will lie at about 20°C over the air temperature.

4.4 Degradation and soiling

PV fields are subject to degradation and soiling. Researches have shown that soiling rapidly increases in the early weeks after installation or cleaning to eventually settle to a level in the range of 2 to 6% (Source: H. Becker, W. Vassen, W. Hermann: „Reduced Output of Solar Generators due to Pollution“. Proc. 14th EU PV Conf., Barcelona, 1997). The soiling rate matches the percentage reduction in the system's DC yield.
The degradation of solar modules as well as that of system as a whole is assumed to be a linear process. Degradation-induced yiled decreases amount to an average 0.2%/year (Source: Leitfaden Photovoltaische Anlagen; Deutsche Gesellschaft für Sonnenenergie, Landesverband Berlin Brandenburg e.V.; DGS Berlin 2005.).

4.5 Results

The yield of a solar system can be calculated by means of the H.G. Beyer model.
(Source: Beyer, H.G., Betcke, J., Drews, A., Heinemann, D., Lorenz, E., Heilscher, G., Bofinger, S., 19th European Photovolatic Solar Energy Conference & Exhibition, Paris 7.6.-11.6.2004. Identification of a General Model for the MPP Performance of PV-Modules for the Application in a Procedure for the Performance Check of Grid Connected Systems). This model relies on the following inputs:

- 3 efficiency readings for the module at different irradiance conditions.
- 3 efficiency readings for the inverter with different loads
- The installed power
- The module's temperature coefficient

Such interpolation nodes enable an efficiency curve to be identified for the module and the inverter These curves, the installed power and the temperature coefficients allow the yield to be calculated depending on the irradiance and module temperature.

Model temperature can be calculated from ambient temperature, irradiance and gamma parameter for rear ventilation:
Module temperature = ambient temperature + gamma x irradiance/1000 W/m2

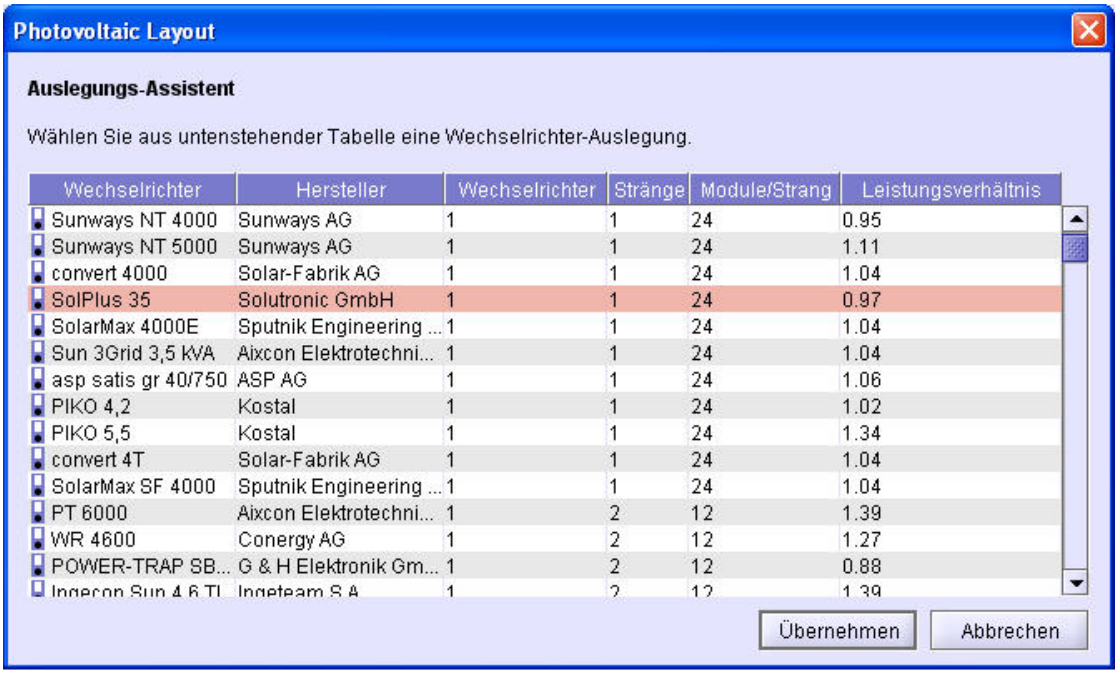
The following factors may be inferred from the resulting yield:

- Soiling (default value 2%, it can be defined in the PV field)
- Degradation (default value 0.2%, it can be defined in the PV field)
- Standard deduction for piping lossess, module mismatch and module derating: 4% + 4% x inverter load

4.6 Inverter configuration

Polysun provides users with a useful inverter configuration tool, the “Inverter assistant“. The “Inverter assistant” can be started both via the provided assistants (photovoltaics page) and by means of the photovoltaic or PVT components (double-click on the relevant component and subsequent single click on the assistant symbol)

The inverter assistant provides the user with a list of possible configurations (hereafter called “Configuration variants).


Photovoltaic Layout
Auslegungs-Assistent
Wählen Sie aus untenstehender Tabelle eine Wechselrichter-Auslegung.
Wechselrichter | Hersteller | Wechselrichter | Stränge | Module/Strang | Leistungsverhältnis
Sunways NT 4000 | Sunways AG | 1 | 1 | 24 | 0.95
Sunways NT 5000 | Sunways AG | 1 | 1 | 24 | 1.11
convert 4000 | Solar-Fabrik AG | 1 | 1 | 24 | 1.04
SolPlus 35 | Solutronic GmbH | 1 | 1 | 24 | 0.97
SolarMax 4000E | Sputnik Engineering ... | 1 | 1 | 24 | 1.04
Sun 3Grid 3,5 kVA | Aixcon Elektrotechni... | 1 | 1 | 24 | 1.04
asp satis gr 40/750 | ASP AG | 1 | 1 | 24 | 1.06
PIKO 4,2 | Kostal | 1 | 1 | 24 | 1.02
PIKO 5,5 | Kostal | 1 | 1 | 24 | 1.34
convert 4T | Solar-Fabrik AG | 1 | 1 | 24 | 1.04
SolarMax SF 4000 | Sputnik Engineering ... | 1 | 1 | 24 | 1.04
PT 6000 | Aixcon Elektrotechni... | 1 | 2 | 12 | 1.39
WR 4600 | Conergy AG | 1 | 2 | 12 | 1.27
POWER-TRAP SB... | G & H Elektronik Gm... | 1 | 2 | 12 | 0.88
Übernehmen
Abbrechen
Figure 7: Inverter configuration

Starting situation:
The following data are given in the calculation of configuration variants:

- Location
- Type of module
- Number of modules

Additionally the following values will also be considered in the calculation of the max. DC power (and partially also for the calculation of the min. and max. module temperature and therefore the max. MPP voltage and the max. DC current): orientation, , tilt angle, level of soiling, degradation, wind percentage and rear ventilation.

Configuration result – Configuration variants:
Configuration variants are characterised through the following data:

- Type of inverter
- Number of inverters
- Number of MPP trackers employed
- Number of strings (per inverter or MPP tracker)

Number of MPP trackers employed:
In case multi-string inverters are used Polysun attempts to reach the full or partial allocation of all MPP-controlled inputs. The configuration programme assumes here that strings were allocated uniformly.
Additionally the following data will also be displayed in the inverter assistant:
inverter manufacturer, number of modules per string and power ratio.

Power ratio:
The term “power ratio“ refers in Polysun to the ratio between generator output at standard test conditions (STC) and the inverter’s maximum DC output.

Electrical limit values:
Configuration variants are essentially selected based on the relevant electrical limit values. Polysun basically only reproduces combinations that comply with the limit values specified below (occasionally subject to particular operation and weather conditions). Voltage and current peaks can be calculated by means of the temperature coefficients included in the catalogue.

Nr.	Component	Limit value	Mode	Weather conditions
1	Inverter	Max. DC output		Max. irradiance
2	Inverter	Max. DC voltage	Idling	Min. air temperature
3	Inverter	Min. MPP voltage	MPP	Max. air temperature
4	Inverter	Max. MPP voltage	MPP	Min. module temperature
5	Inverter	Max. DC current	MPP	Max. module temperature
6	Module	Max. system voltage	Idling	Min. air temperature
7	Mains	Max. phase imbalance		

Module temperature calculation:
Polysun enables module temperature to be calculated by the user. The following data are considered in the calculation: air temperature, irradiance, module gamma, wind percentage and rear ventilation.
If PVT collectors are used a fixed minimum (10 °C) and maximum temperature (80 °C) are assumed for inverter configuration purposes.

Phase imbalance:
The configuration variants provided by the configuration assistant comply with the requirement for a maximum phase imbalance of 4.2 kVA.

Thin-film modules – Galvanic separation:
Thin-film modules should only be operated with a transformer or galvanic separation. This applies to all inverter configurations.

Filters/Tolerances:
Configuration variants are eventually filtered, i.e. only given tolerance values will be allowed.

Filters/Tolerances inverter assistant:
The following fixed-sized filters will be used in the inverter assistant:
0.75 <= power ratio <= 1.25.
Additionally a fixed tolerance of 10% is given fort he maximum input power. A tolerance of 0% applies to all remaining maximum values.

4.7 Electric consumers and internal grid

The component *Electric consumers and internal grid* depicts a system's internal grid and the relevant electric consumers. This component plays a key role in the simulation of electric systems.

Electrical consumption profiles
In the component *Electric consumers and internal grid,* the electrical consumption may be specified by means of suitable consumption profiles. Multiple consumption profiles may be selected and respectively added to a specific time step.

Consumption profiles may be scaled to an annual value. The value “0“ resets the annual consumption to the original profile value.

If no electrical consumption is available, the number of consumption profiles may be set to “0”.

In Polysun, profiles feature regular time steps. Two different time steps are supported:

- Each hour
- Each 15 minutes

The electrical consumption for a given time step is specified in kWh.
As the software supports 15-minute profiles, smart-meter measurements may be easily used in Polysun.

A wide range of pre-defined profiles are available for use in Polysun.
User-defined profiles may also be added, including, for example, any available reference profiles. If the simulation of a given system requires that a special profile be used, this may be created, for example, using the *Load Profiles Generator* programme.[1] This software generates profiles based on a so-called “desire model“, allowing the creation of a wide range of profiles.

Electrical consumption of thermal components
In addition to the default load profiles, the software also allows for the electrical consumption of thermal components to be taken into account. To this end, the feature *Thermal components with electrical consumption* may be enabled by the user in the component *Electric consumers and internal grid.* This feature will only be displayed if thermal components are available in the system.

The following thermal components will be included in the electrical consumption if the feature is enabled:

Component	**Value**
Heat pump	Eaux
B/W or W/W heat pump	Eaux
Pump	Epar
Internal heat generator (electric)	Eaux
Recooler	Fan speed

Calculation of self-consumption
The component *Electric consumers and internal grid* allows for the calculation and display of various self-consumption values. The respective tool-tips (hover with the mouse over the item for 2 seconds) display the definition of the value as well as the calculation on which it is based.

The percentage of self-consumption may be significantly increased by means of appropriate energy storage systems (batteries).

4.8 Batteries

Batteries are used to store electrical energy.
Polysun supports commonly used, inexpensive lead batteries.

1 http://www-user.tu-chemnitz.de/~noah/index.php

Batteries are used for self-consumption optimization purposes as well as in self-sustaining, off-grid systems.
Batteries are also called accumulators.

Lead batteries/KiBa model (KiBaM)
In Polysun, lead batteries are displayed according to the *Kinetic Battery Model* (KiBaM). In the KiBaM, batteries are assumed to be a two-tank electrical energy storage device, the first containing readily available electrical energy, the second containing slower chemical energy which is converted into electrical energy at a limited rate.

The model implemented in Polysun is that suggested by Vrettos & Papathanassiou (Operating policy and optimal sizing of a high penetration RES-BESS system for small isolated grids, 2011) which describes energies and performances. Voltage variations are not displayed. The paper (Vrettos, Witzig, Kurmann, Koch, & Andersson, 2013) directly addresses how the model is implemented in Polysun.

According to Vrettos & Papathanassiou (Operating policy and optimal sizing of a high penetration RES-BESS system for small isolated grids, 2011), we work at a constant battery voltage. The available and the chemically bound energy at the end of a time step are given by:

$$E_{1,t+1} = E_{1,t}\, e^{-k\Delta t} + \frac{(E_{0,t} \cdot k \cdot c - P) \cdot (1 - e^{-k\cdot\Delta t})}{k} - \frac{P \cdot c \cdot (k \cdot \Delta t - 1 + e^{-k\cdot\Delta t})}{k}$$

$$E_{2,t+1} = E_{2,t}\, e^{-k\cdot\Delta t} + E_{0,t}(1-c) \cdot (1 - e^{-k\cdot\Delta t}) - \frac{P \cdot (1-c) \cdot (k \cdot \Delta t - 1 + e^{-k\cdot\Delta t})}{k}$$

$$E_{0,t} = E_{1,t} + E_{2,t}$$

where Δt is the time step duration in hours, E1,t E2,t and E0,t are the available, chemically bound and total electrical energy stored in the battery. P is the charge/discharge power. c=E1,t/E2,t is the capacity ratio parameter. k is the rate constant parameter that corresponds to the rate at which chemically bound energy becomes available for output. Conventionally, in this battery model P is positive during discharging and negative during charging.
The KiBaM also models the maximum charge (Pch,max) and discharge (Pdis,max) power as a function of the stored energy:

$$P_{dis,max} = \frac{k \cdot E_{1,t} \cdot e^{-k\cdot\Delta t} + E_{0,t} \cdot k \cdot c \cdot (1 - e^{-k\cdot\Delta t})}{1 - e^{-k\cdot\Delta t} + c \cdot (k \cdot \Delta t - 1 + e^{-k\cdot\Delta t})}$$

$$P_{ch,max} = \frac{-k \cdot c \cdot E_{max} + k \cdot E_{1,t}\, e^{-k\cdot\Delta t} + E_{0,t} \cdot k \cdot c \cdot (1 - e^{-k\cdot\Delta t})}{1 - e^{-k\cdot\Delta t} + c \cdot (k \cdot \Delta t - 1 + e^{-k\cdot\Delta t})}$$

where Emax is the nominal battery capacity. With this notation, the State of Charge (SOC) is defined as:

$$SOC_t = \frac{E_{0,t}}{E_{max}}$$

In Polysun, batteries are connected to the AC side and are equipped with their own inverter. Inverters are depicted by means of simple efficiencies.

The self-discharge of batteries is depicted as a linear decrease in charge.

New battery models can also be added to the catalogue. If the c and k parameters are not available, they may be calculated from three discharge curves, each with a constant power load. The calculation may be performed using the *Battery Parameter Finder* programme[2].

Battery lifetime estimation
The ROI (Return of Investment) of batteries depends on their lifetime. Therefore, the lifetime of a battery may be estimated based on the number of charge/discharge cycles (Rainflow Cycle Counting Method). This estimation assumes the lifetime of a battery to depend on the depth and number of charge/discharge cycles.
The relationship between cycle depth and number of cycles to failure is usually shown in the battery datasheet:

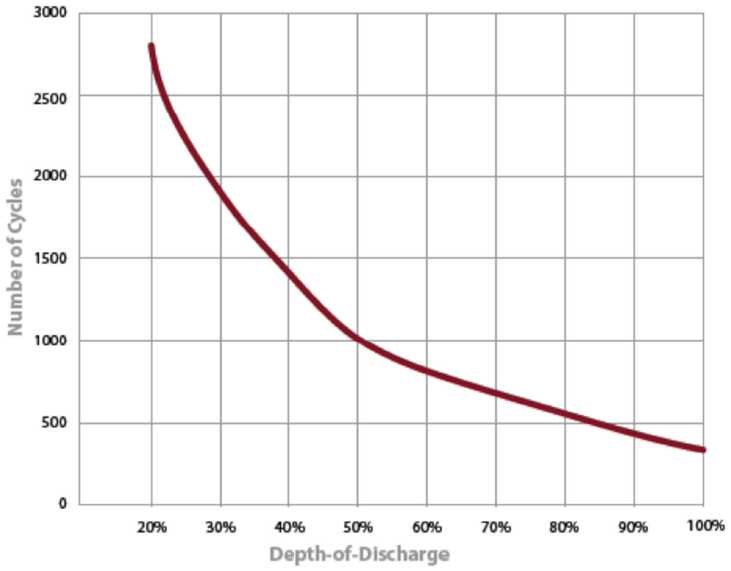


Figure : typical curve showing the relationship between the number of cycles and discharge depth as indicated in a battery datasheet

In Polysun, the relationship between the number of cycles to failure (*C*FL) and the range (*R*) of charge/discharge cycles is modelled via a double exponential function:

$$C_F = \alpha_1 + \alpha_2 \cdot e^{-\alpha_3 \cdot R} + \alpha_4 \cdot e^{-\alpha_5 \cdot R}$$

Parameters α1 to α5 can be directly provided by the battery manufacturer, or obtained via non-linear regression on empirical lifetime test data as shown in the datasheet charts. Parameters α1 to α5 are optional. No lifetime estimation can be made if these are not available.

To calculate the lifetime in Polysun, we use 20 bins of equal size, each tallying the number of cycles of the relevant range. Mi denotes the annual number of cycles with Ri range. CFL,i denotes the respective number of cycles to failure of a Ri range. With each battery cycle, 1/CFL,i of the entire battery lifetime is consumed. Therefore, the cumulative annual damage D is determined by:

2 http://www.umass.edu/windenergy/research.topics.tools.software.kibam.php

$$D = \sum_i \frac{M}{C_{FL,i}}$$

For instance, if, at the end of the annual simulation, D=0.5, the battery is half-way through its lifetime. In other words, the battery will need to be replaced every two years. Since battery lifetime is drastically affected by deep discharge cycles, only part of the available capacity is used for daily cycling. The battery is never discharged deeper than SOCmin. A SOC≥SOCmin constraint applies. The SOCmin value is type-specific and can be obtained form the manufacturer's data sheet.

Simulation results for the batteries show both the total number of cycles run and the deep cycles. In the battery properties dialogue box, a deep cycle threshold defines what may be classified as "deep discharge".

Controller

In Polysun, batteries are equipped with an automatic controller as a standard. If necessary, the battery may also be controlled by means of the available programmable controller.

The controller works based on a calculation of the system's net power $P_n(t)$ = *generated power – consumed power*.

Automatic controllers work on this basic principle: the battery is charged when a sufficient amount of self-generated power is available and discharged as soon as a power deficit occurs. The battery is never charged off the mains.

Description of an *automatic controller*:

1. When the system generates an amount of power in excess of what is consumed ($P_n(t) > 0$) the following charge pattern applies:
    a. Charge battery with maximum possible, available power as long as it can be charged.
    Pch(t)=min [Pnt, Pch,maxt]
    b. Feed remaining power into the grid.
    Ptegt=Pnt-Pcht
2. When the system consumes more power than it generates ($P_n(t) > 0$) the following discharge pattern applies:
    a. Discharge battery to maximum possible extent as long as it can be discharged.
    Pdis(t)=min [|Pnt|, Pdis,maxt]
    b. Draw the remaining power from the grid.
    Pfegt=Pnt+Pdist

The battery offers two inputs for the programmable controller:

Input	Description	Value
Control mode	Shows how the battery is controlled	0: automatic controller (default value) 1: controlled battery power is used
Controlled power	Battery power may be set.	> 0: the battery is charged, value in [W] <=: the battery is discharged, value in [W]

Template 50h provides an example of explicit battery control.

PV-performance ratio parameter (self-consumption optimisation)
The *PV-performance ratio* input parameter appearing in the battery properties dialogue box may be used for self-consumption optimisation purposes. This value refers to the ratio the between current and nominal PV performance. In Germany, for example, feed-in amounts in excess of 70% of the nominal PV-performance are associated with lower feed-in tariffs. The purpose of this controller is to pull down midday-peak electricity demand. The *PV-performance ratio* parameter is used to define a threshold value which, in turn, defines the time from which the battery is to be charged. If the threshold value is set to 0%, the battery will always be charged. If the threshold value is set to 70%, the battery will only start charging from 70% of the nominal PV-performance.
In template 50h, the same pattern is implemented with a progressive controller which also takes SOC into account. To this end, the photovoltaic component provides the user with the *PV-performance ratio* output parameter.

4.9 Grid-connected or off-grid systems

Polysun supports the simulation of both grid-connected and self-sustaining off-grid systems.
The presence of the *External grid* component (“power pylon“) indicates a grid-connected system. The absence of this component is suggestive of an off-grid system.
Although the calculation is performed in the same way both for on and off-grid systems, results are, however, interpreted and shown differently.

5 Thermal systems

This section provides an overview of the basic simulation-algorithms used in Polysun for thermal components as well as useful background information on the physical models to be implemented.

5.1 Solar fractions

When viewing “Results for the variant” the different solar fractions SFi (input oriented), SFn (net) and SFg (gross) are displayed. These refer to diverse limits of the system, see fig. 5. Only those solar fractions for the variants that can be automatically calculated are displayed.

$$SFi = \frac{Solar\_energy\_to\_storage\_tank}{Solar\_energy\_to\_storage\_tank\_+ Auxiliary\_energy\_to\_storage\_tank} = \frac{S_{sol}}{S_{sol} + S_{aux}}$$

$$SFn = \frac{Solar\_energy\_to\_the\_system}{Solar\_energy\_to\_the\_system\_+ Auxiliary\_energy\_to\_the\_system} = \frac{Q_{sol}}{Q_{sol} + Q_{aux}}$$

$$SFg = \frac{Irradiance\_onto\_collector\_area}{Irradiance\_onto\_collector\_area\_+ Auxiliary\_energy} = \frac{E_{sol}}{E_{sol} + E_{aux}}$$

For the purpose of the analysis of the system’s behaviour it is sometimes required that the solar

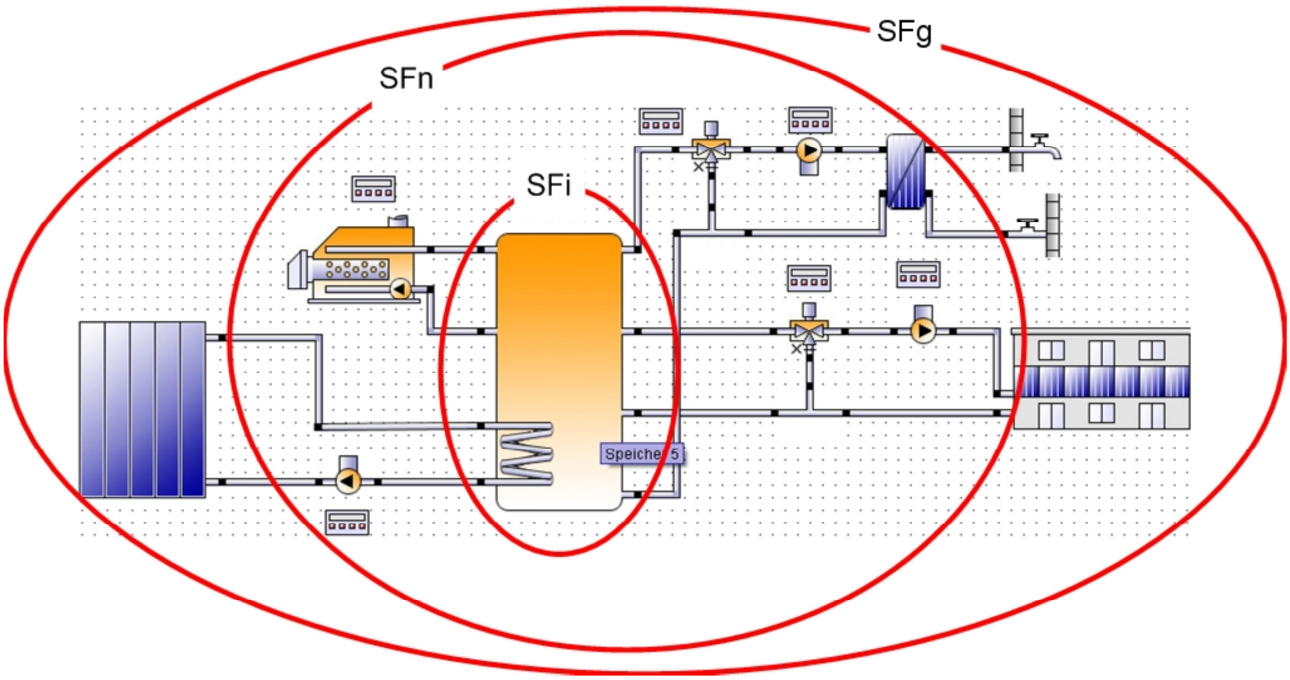


Figure 8: limits for the calculation of solar fractions

fraction for hot water and heating are specified separately. This is only possible for special system configurations where the heat for heating and hot water are run and stored separately. In systems equipped with return flow bypass or with a tank used as a hydraulic compensator choosing whether in the consumer the heat was generated at some point at an earlier time-interval through the solar collectors or the auxiliary heating is not possible.

Polysun employs just like Polysun 3 an approximate calculation method that may be applied in all situations. The separate specification of solar fraction for hot water and heating is based on the weighting of the overall solar fraction with the heat demand over a defined time interval.

$$S_{Fn}^{Heiz} = \frac{\sum_i S_{Fn}^i \cdot Q_{Heiz}^i}{\sum_i Q_{Heiz}^i}$$

$$S_{Fn}^{WW} = \frac{\sum_i S_{Fn}^i \cdot Q_{WW}^i}{\sum_i Q_{WW}^i}$$

In this context Polysun uses for the calculation a variable time-interval ranging from two days to two weeks. The output result will be simply a yearly value as monthly values would not be meaningful.

Interpretation example: During the summer months the heat demand from the heating system is very low and the solar faction is therefore relevant only for the hot water.

Discussion: If compared with the direct calculation (separate buffer tanks) the solar fractions achieved by means of the above formula are much closer. The separated solar fractions of further consumers (like e.g. swimming pool or solar cooling system) may be defined in analogous manner.

Recommendation: Use *reference systems*! The specification of separate solar fractions has no significance for design or customer service purposes. A much more crucial role will be played by the use of the *reference systems* offered as a standard in Polysun. This will enable to elicit the influence of single system components and to optimize the heating system. See paragraph 2.2 on page 8.

5.2 Denominations and representation of the results

The abbreviations for the energy balances are always based on the same model. Therefore “QparS” means the heat energy transferred from the pump to the solar loop.

> “Q” stands for the energy transferred to the system, or rather to the hydraulic system, “par” for parasitic energy and “S” for the circuit, in this case, the solar loop. If the last index is missing, here S, it is meant the transferred heat energy to all loops by all available pumps.

The meaning of the various letters of the alphabet and the positions are explained in the table below.

Heat loss to interior space “Qint” means the losses of all the components present indoors, also including the chemical energy losses in boilers with less than 100% efficiency.

“Qdem” is the energy demand, calculated by Polysun, that should be possibly covered. In the case when the “Quse” (the effective energy consumption) is lower than the “Qdem”, the energy demand can’t be covered and the corresponding warning appears. The causes are sought primarily in the installation height of the connections in the boiler or of controller settings. The availability of hot water and building heating shown in the component results indicate what percentage of energy demand is covered.

In case of the collector, the end energy “Esol” is referring to the gross collector surface irradiation. “Eaux” means the chemical energy (highest value of heat of combustion) of combustible fuel.

Letter position	Letter	Definition
1	E	End energy (fuel and electrical power consumption)
	Q	Energy to the system or energy withdrawn from the system
	S	Energy to the tank or energy withdrawn from the tank
2. to 4.		
	sol	Solar energy (example: Qsol = Energy supplied from collector to fluid)
	out	Energy withdrawn
	use	Energy consumption (amount of energy actually consumed for domestic hot water, swimming pool, building and heat sink)
	dem	Energy demand (theoretically calculated value referring to the amount of energy required, for example, to heat the cold water of the cold water piping to the desired hot water temperature)
	aux	Auxiliary energy (energy of heat generators or electrical air-conditioning devices, for example Qaux = energy supplied from heat generator to fluid)
	par	Auxiliary or parasitic energy (pumps and fans)
	int	Energy to indoor room (all components placed indoors, for example Qint = heat loss to indoor room)
	ext	Energy to surroundings (all components placed outdoors, for example Qext = heat loss to surroundings)
	def	Energy deficit (difference between energy demand and energy consumption)
	xfr	Transferred energy
	ventil	Energy in ventilation of building
	trans	Energy transmission in building
5	S	Solar
	A	Auxiliary
	X	Heat transmission
	U	User
	M	Midex (solar and auxiliary)
		Total of all loops

Fluid overview

The various loops of the system with all of their respective components and fluids are listed. In this window the fluid can also be modified at any time. All you need to do is select a fluid and click on “Change heat transfer medium”.

Result overview

An overview of primarily used results is given. By selecting a result, the respective graph with monthly values is displayed at the bottom of the window.

System results
The results of the various loops are listed in this window. In the overview there are the solar fractions as well as the respective energies and how they are determined.

Description	Abbrev.	Meaning
Energy consumption	Quse	Amount of energy actually consumed by a consumer unit. This includes energy consumption for domestic hot water, swimming pool, building heating and cooling as well as heat sink, provided the latter is a consumer unit. All values are added to a total amount (positive values).
Energy demand	Qdem	Amount of energy required by consumer units to ensure that the required comfort conditions are met. This includes energy demand for domestic hot water, building heating and cooling as well as heat sink, provided the latter is a consumer unit. All values are added to a total amount (positive values).
Energy supplied from heat generators to system (inclusive of air-conditioning devices)	Qaux	Amount of energy supplied from electrical and fuel-operated heat generators and electrical air-conditioning devices to fluid.
Fuel and power consumption by heat generators and air-conditioning devices	Eaux	Amount of fuel and electrical power required by heat generators and electrical air-conditioning devices.
Overall fuel and electrical power consumption	Etot	Amount of fuel and electrical power required by heat generators, electrical air-conditioning devices, pumps, fans, etc.

Component results
The results of each individual component are shown in average monthly and annual values, as well as maximum and minimum values. These latter values are useful above all for the pipes, in which the average temperature has less importance than the effective temperature at the time of flow. This visualization is possible at the Professional and the Designer level.

Hourly values
This is the display of all hourly values in the form of a chart. It is possible to select the series of data by clicking on the title, copying with “Ctrl-c” and inserting it in Excel. This visualization is possible at the Designer level.

Graphical evaluation
The graphic tool of Polysun (Professional and Designer level) offers the possibility of having a visual analysis of the data. The following values can be represented, on the basis of hourly values, for any period of time (year, month, hour and intermediate periods):

- All temperatures
- All power values
- All flow rates
- All on-off statuses
- All Sfg solar fractions

The temporal scale can be freely selected by opening a box using the mouse. If it is necessary to display more than one scale (for example one for temperature and one for power value), these are visualized to the left and to the right of the graphic chart and one or the other can be dragged vertically and independently. If in addition you add one of the values without units “solar fraction” or “pump activity”, the temperature is spread from 0 – 100 and the corresponding value is represented in %.

The consumption values, such as hot water consumption, the heating energy demand and the night cool-off temperature are indicated with a negative sign.

Suggestions: The results are of average hourly values and might not be precisely represented over the course of an entire year. A year contains 8760 hours, a screen has many fewer pixels. Therefore in the visualization of the year the values become averages over more hours. This creates confusion above all regarding the temperature of the collector. Consequently a time frame as brief as possible is to be selected.

The values that change in the course of an hour are equally difficult to interpret. If the pump is activated for five minutes, the status will be indicated in the entire hour as 1, that is,”on”. The

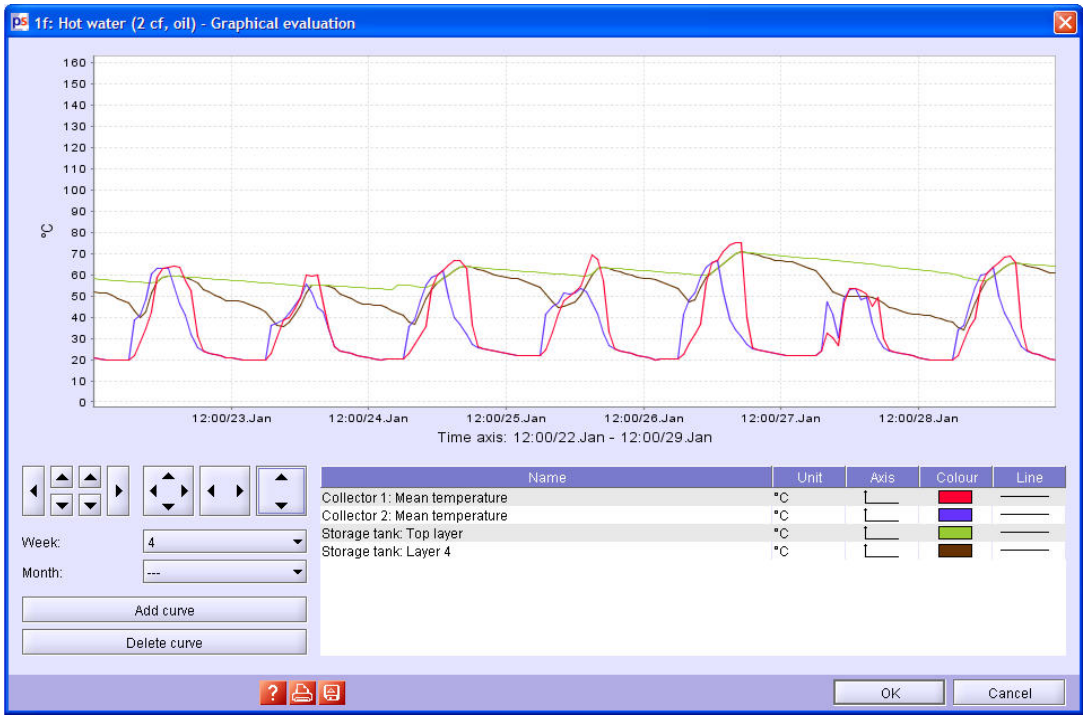


Figure 9: graphical evaluation of simulation results

effective operation time of the pump can only be evident in the visualization of the component results.

Report

The different types of report – short report, professional report, comparative report and economic viability report – summarize all relevant results within a single document. The following example outlines the results shown in the report.

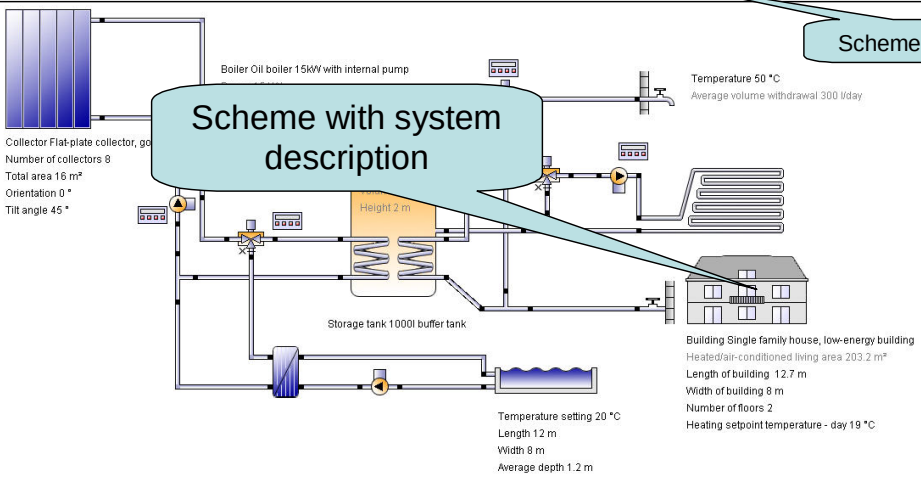
Professional Report

Company logo

Your Logo

1 **10a: Space heating + ~~pool~~ (solar thermal, high-flow)**

Scheme name


Boiler Oil boiler 15kW with internal pump
Temperature 50 °C
Average volume withdrawal 300 l/day
Collector Flat-plate collector, go
Number of collectors 8
Total area 16 m²
Orientation 0 °
Tilt angle 45 °
Height 2 m
Storage tank 1000l buffer tank
Building Single family house, low-energy building
Heated/air-conditioned living area 203.2 m²
Length of building 12.7 m
Width of building 8 m
Number of floors 2
Heating setpoint temperature - day 19 °C
Temperature setting 20 °C
Length 12 m
Width 8 m
Average depth 1.2 m

Scheme with system description

Location of the system

USA
CA San Francisco
Longitude: -122.42°
Latitude: 37.78°
Elevation: 16 m

Installation site

Name & address of planner

This report has been created by:

Andreas Wolf
Via Assisana 40
06135 Piscille di Perugia (PG)

Total fuel and power consumption required for operation (heat generators, chillers, pumps, fans)

System overview (annual values)

Total fuel and/or electrical energy consumption of the system [Etot]	754.8 kWh
Total energy consumption [Quse]	8,151.1 kWh
System performance (Quse / Etot)	10.8
Comfort demand	Energy d… and …

Amount of actually consumed energy (consumers are domestic hot water, heating, cooling, swimming-pool, process-heat and supply to a district heating network)

If the respective temperatures are exceeded by more than 5% for 5% of the time, the message “Energy demand not met“ is shown. For a correct comparison between different systems the energy demand must always be met.

This enables an objective comparison between different systems. The higher the value, the better the result.

…ccept any liability for the correctness of the … results.

Aggregate of all collector fields

Percentage of total generated energy coming from solar sources. 98.2% of the energy need was met through solar energy. [Qsol / (Qsol+Qaux)]

An average 97.8% of the energy required for hot water was supplied by solar energy.

erage 97.8% of the energy quired for space heating was supplied by solar energy.

Annual amount of energy supplied by collectors to the system (loop).

Specific annual amount of energy supplied by collectors to the system (loop) per effective collector surface

Annual fuel savings through use of solar thermal technology.

Annual fuel savings through the use of solar thermal technology, converted in kWh. This value can be higher than the collector field yield as this is also divided by boiler efficiency.

Specific annual amount of energy supplied to the system (loop) per gross collector surface.

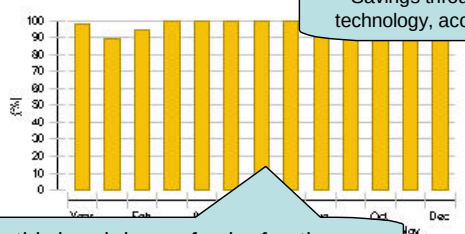
Savings through the use solar thermal technology, accordingly converted in CO2

Overview sol thermal energ values)

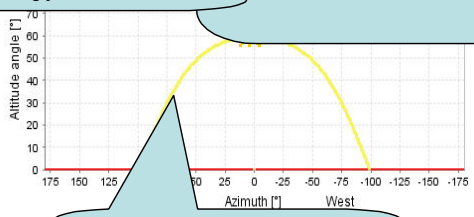
Collector area	16 m²
Solar fraction total	98.2%
Solar fraction hot water [SFnHw]	97.8 %
Solar fraction building [SFnBd]	97.8 %
Total annual field yield	10,803 kWh
Collector field yield relating to gross area	675 kWh/m²/Y
Collector field yield relating to aperture area	750 kWh/
Max. fuel savings	1,271.1 l: [Heating oil]
Max. energy savings	12,709.9 kWh
Max. reduction in CO2 emis	3,821.5 kg

stem H

[SFnH]



Monthly breakdown of solar fraction



Reduced yields through horizon and nearby shading are taken into account.

Meteorological data-Overview

Outdoor temperature 24h	14.4 ℃
Annual global irradiance	1,720.9 kWh/m²
Annual diffuse irradiance	645.5 kWh/m²

Average annual outdoor temperature (average in 24 hours)

Total annual radiation on a horizontal surface, in a defined location, per square meter or foot

Percentage of global radiation scattered on clouds and mist particles. The value is equal to the global radiation minus direct radiation.

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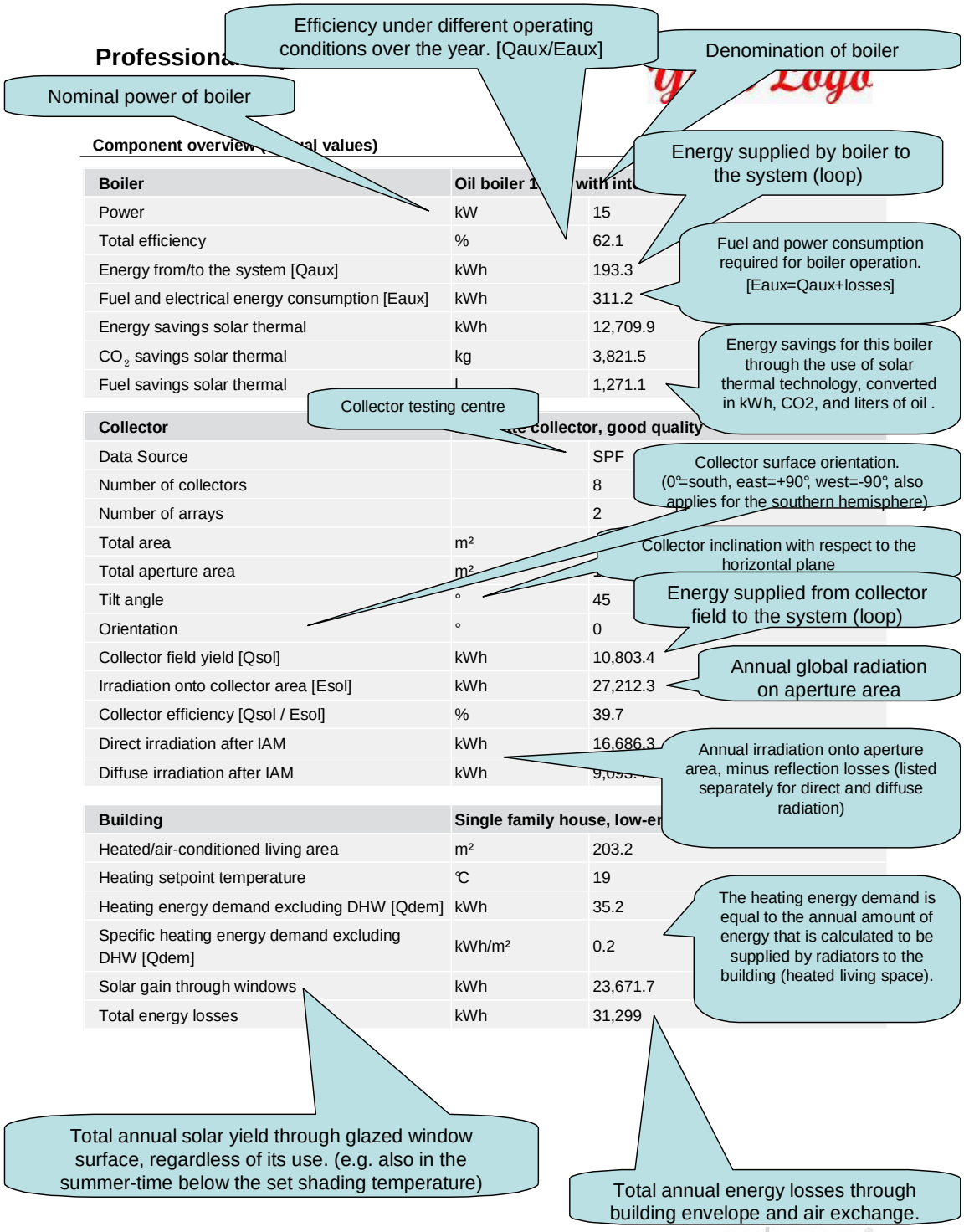
Efficiency under different operating conditions over the year. [Qaux/Eaux]
Denomination of boiler
Nominal power of boiler
Energy supplied by boiler to the system (loop)
Fuel and power consumption required for boiler operation. [Eaux=Qaux+losses]
Energy savings for this boiler through the use of solar thermal technology, converted in kWh, CO2, and liters of oil .
Collector testing centre
Collector surface orientation. (0°=south, east=+90°, west=-90°, also applies for the southern hemisphere)
Collector inclination with respect to the horizontal plane
Energy supplied from collector field to the system (loop)
Annual global radiation on aperture area
Annual irradiation onto aperture area, minus reflection losses (listed separately for direct and diffuse radiation)
The heating energy demand is equal to the annual amount of energy that is calculated to be supplied by radiators to the building (heated living space).
Total annual solar yield through glazed window surface, regardless of its use. (e.g. also in the summer-time below the set shading temperature)
Total annual energy losses through building envelope and air exchange.

Professiona

Component overview (al values)

Boiler	**Oil boiler 1**	**with int**
Power	kW	15
Total efficiency	%	62.1
Energy from/to the system [Qaux]	kWh	193.3
Fuel and electrical energy consumption [Eaux]	kWh	311.2
Energy savings solar thermal	kWh	12,709.9
CO_2 savings solar thermal	kg	3,821.5
Fuel savings solar thermal	l	1,271.1

Collector		**e collector, good quality**
Data Source		SPF
Number of collectors		8
Number of arrays		2
Total area	m²	
Total aperture area	m²	
Tilt angle	°	45
Orientation	°	0
Collector field yield [Qsol]	kWh	10,803.4
Irradiation onto collector area [Esol]	kWh	27,212.3
Collector efficiency [Qsol / Esol]	%	39.7
Direct irradiation after IAM	kWh	16,686.3
Diffuse irradiation after IAM	kWh	9,093.7

Building	**Single family house, low-er**	
Heated/air-conditioned living area	m²	203.2
Heating setpoint temperature	℃	19
Heating energy demand excluding DHW [Qdem]	kWh	35.2
Specific heating energy demand excluding DHW [Qdem]	kWh/m²	0.2
Solar gain through windows	kWh	23,671.7
Total energy losses	kWh	31,299

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Professional Report

Convector Floor heating	Floor heating 1000W	
Number of heating/cooling modules	-	13
Power per heating module under standard conditions	W	1,000
Nominal inlet temperature	℃	40
Nominal return temperature	℃	35
Net energy from/to heating/cooling modules	kWh	-0.3

Hot water demand	Constant	
Withdraw volume	l/d	301.5
Temperature setting	℃	50
Energy from/to the system [Quse]	kWh	4,658.8

Pool Pool	Outdoor pool	
Pool type		Outdoor pool
Length	m	12
Width	m	8
Energy from/to the system [Quse]	kWh	3,457.1

External heat exchanger Pool heat exchanger	Plate heat exchang	
Transfer capacity	W/K	5,000

Pump Solar loop pump	Pump, medium	
Circuit pressure drop	bar	0.536
Flow rate	l/h	576
Fuel and electrical energy consumption [Epar]	kWh	216.8

Pump Pool pump	Pump, large	
Circuit pressure drop	bar	0.021
Flow rate	l/h	520
Fuel and electrical energy consumption [Epar]	kWh	226.8

Total maximum power output is equal to the number of heating/cooling modules times the power

Amount of energy supplied to the building by floor heating over the year.

Daily hot water consumption (leap years considered)

Amount of energy actually required to bring the cold water to the desired temperature

Unit of measurement for heat exchanger size. (eg. with a transmission power of 10 kW, the temperature drop from supply to demand side is equal to 2 K)

Average flow rate in operation

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Storage tank Solar buffer tank	1000l buffer tank	
Volume	l	1,000
Height	m	2
Material		Steel
Insulation		Rigid PU f
Thickness of insulation	mm	80
Heat loss	kWh	936.8
Connection losses	kWh	1,072.8

Annual heat loss through walls

Annual heat loss through connections

Loop

Solar loop		
Fluid mixture		Ethylene mixture
Fluid concentration	%	33.3
Fluid domains volume	l	59.3
Pressure on top of the circuit		

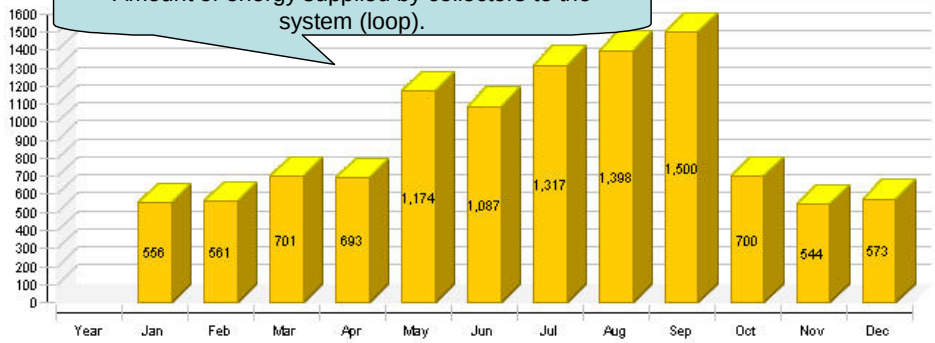
33% ethylene; the rest is water

Pressure affects the evaporation point

59.3 l of glycol are required to fill the solar loop

Solar thermal energy to the system [Qsol]

Amount of energy supplied by collectors to the system (loop).



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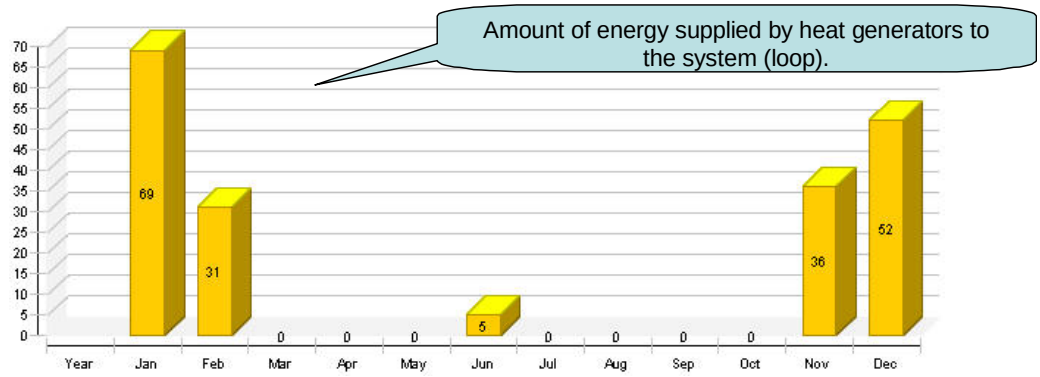
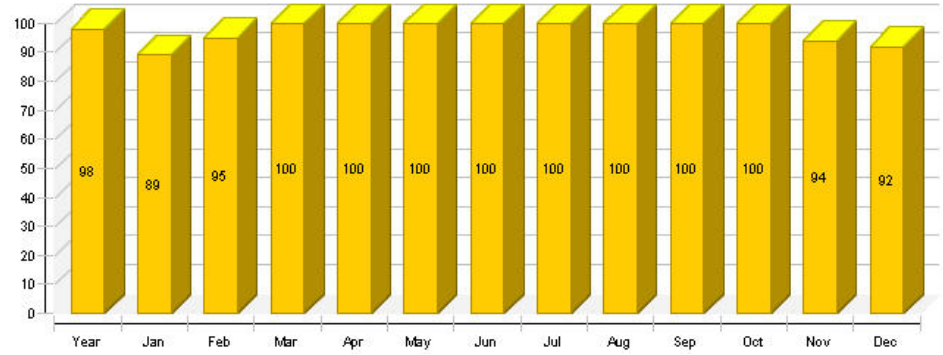
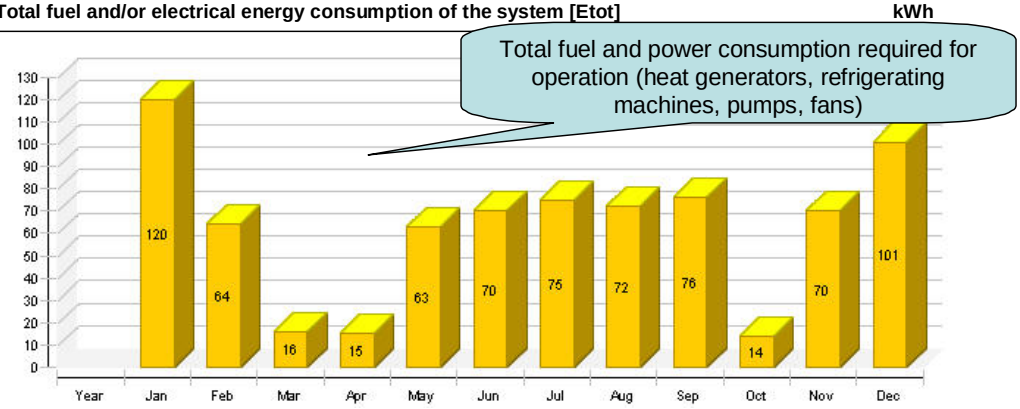
Heat generator energy to the system (solar thermal energy not included) [Qaux] **kWh**



Solar fraction: fraction of solar energy to system [SFn] **%**



Total fuel and/or electrical energy consumption of the system [Etot] **kWh**



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Professional Report

Your Page

	Year	Jan	Feb	Mar	Apr	May	Jun	Jul					
Solar thermal energy to the system [Qsol]													
kWh	10803	556	561	701	693	1174	1087	1317					
Heat generator energy to the system (solar thermal energy not included) [Qaux]													
kWh	193	69	31	0	0	0	5	0					
Heat generator fuel and electrical energy consumption [F													
kWh	311	107	51	0	0	0	8	0					
Solar fraction: fraction of solar energy to system [SF.]													
%	98.2	88.9	94.7	100	100	100	99.6	100	100	100	100	93.8	91.7
Total fuel and/or electrical energy consumption													
kWh	755	120	64	16	15	63	70						
Irradiation onto collector area [Esol]													
kWh	27212	1654	1705	2254	2448	2598	2495	27			2488	1743	1545
Electrical energy consumption of pumps [Epar]													
kWh	444	13	13	16	15	63	62	75	72	76	14	12	14
Heat loss to indoor room (including heat generator losses) [Qint]													
kWh	3131	247	219	249	260	268	267	285	286	276	295	249	230
Heat loss to surroundings (without collector losses) [Qext]													
kWh	314	22	22	28	30	27		29	30	26	31	23	20
Total energy consumption [Quse]													
kWh	8151	420	387	430	408								

Amount of energy supplied by collectors to the system (loop).

Amount of energy supplied by heat generators to the system (loop).

Total fuel and power consumption required for operation, minus pumps and fans

Percentage of total generated energy coming from solar thermal sources. [Qsol / (Qsol+Qaux)]

Total fuel and power consumption required for operation (heat generators, refrigerating machines, pumps, fans)

Annual irradiation onto the aperture area

Total heat losses from all components installed indooors and outdoors, respectively. (e.g. waste heat from pump, piping losses, etc. To a certain extent, heat losses prove advantageous to heating energy demand.)

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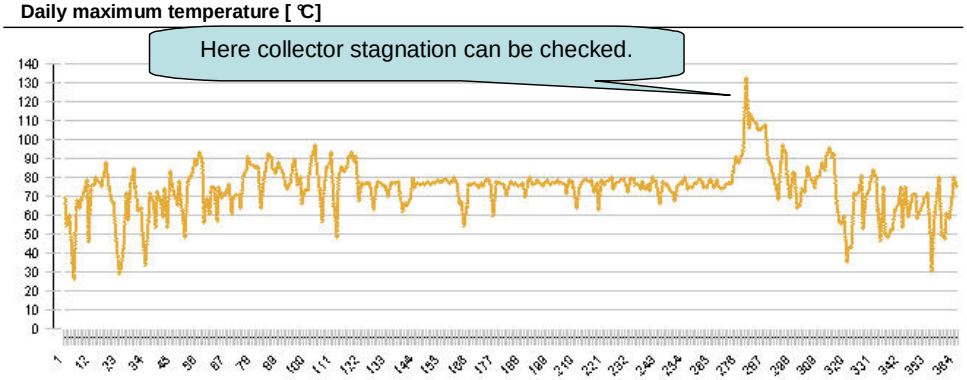
Your Logo

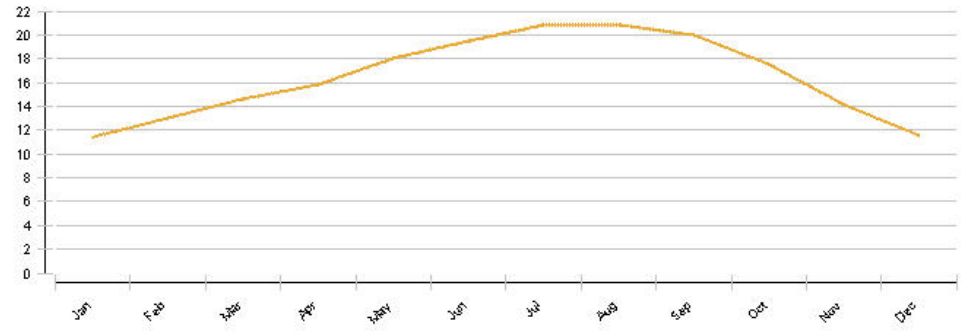
Collector

Daily maximum temperature [℃]



Pool Pool

Monthly average - Temperature [℃]



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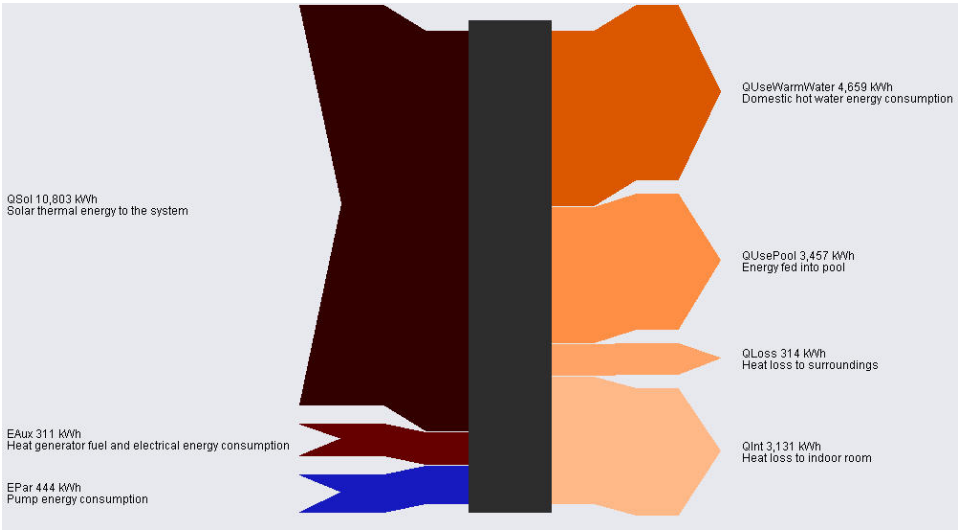
Energy flow diagram



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5.3 Fluid transport

Polysun was designed so as to allow users to create the desired system layout by means of the available components. The first step of the simulation foresees hence a careful analysis of the system layout. The process includes in the sequence the identification of fluid domains and subsequently the identification of fluid loops.

Definition: The term *fluid* refers to the fluid that circulates the different components and transports energy. As fluids often contain different substances Polysun includes a catalogue of main fluid components showing the pure substances (like, for example, water, ethylenglycol, propylenglycol) as well as a fluid mixture catalogue showing the fluids that are actually employed (like, for example, potable water, ethylene mixture, propylene mixture).

Definition: A *fluid domain* is a continuous hydraulic area permeated by a common fluid. A system typically consists of several different fluid domains. System components belonging to a defined fluid domain are circulated by the same fluid.

Definition: A fluid domain consists of one or more *fluid loops*. A fluid loop always includes a flow-rate producer. Results are given for fluid loops (not fluid domains).

Definition: A component is defined as a *flow rate producer* when fluid transport between component connections is determined through physical processes in the same components.
The following components are flow rate producers:

- Pump
- Boiler with inbuilt pump
- Hot water outlet (in which case a direct connection to the cold water outlet may be thought of to close the fluid loop).

Example: The variant *1f: hot water (2 collector fields, heating oil)* should serve as an example for the analysis of the system topology. In this system there are three fluid domains (hot water, auxiliary heating, solar). The solar domain comprises two loops, each one activated by a pump. It is clear that there can be components that belong to two different loops (like the solar coil heat exchanger). On the contrary from the point of view of drinking water, there is only one loop, from the moment that there is only one flow rate producer (the hot water tap) and the three-way valve clearly sets at all times the mix ratio.

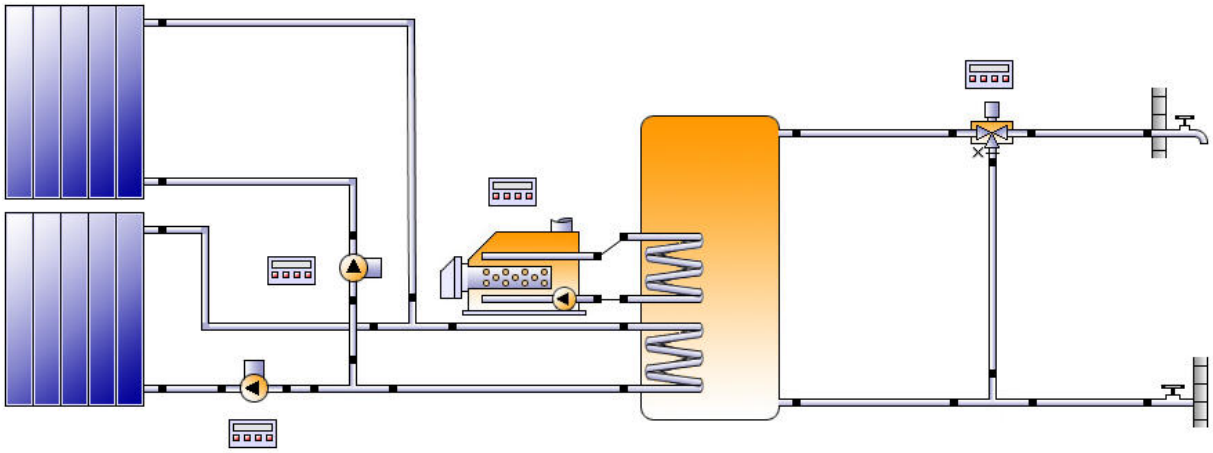


Figure 10: example for fluid domain and fluid loop

The algorithm ensures that the fluid transport is determined for each section of the system in an unequivocal manner. In this way, for example, it prevents two pumps from working counter-productively in the same circuit.

5.4 Solar thermal energy: basic principles, collector types and models

The above mentioned irradiation values naturally cannot be entirely utilized by a collector. There are various factors which contribute to cause one part of the energy not to be transmitted to the heat transfer fluid.

- The partial reflection on the cover glass (approx. 8%), except for uncovered collectors
- The partial absorption by the collector, depending on the coating: minus 4-10 %
- The incomplete cooling of the absorber, the so-called factor F': minus 3-10 %
- The emission of heat by thermal radiation, depending on the coating and the temperature
- The loss of heat by means of thermal conduction and convection, losses depending on temperature

The efficiency of a collector greatly depends on the difference between the average temperature of the collector and the external temperature. If this difference is substantial (i.e 80°C), there are great losses because of thermal radiation and convection. In case of small temperature differences, the efficiency can reach up to approx. 90%. When the temperature of the collector, due to cold fluid, is

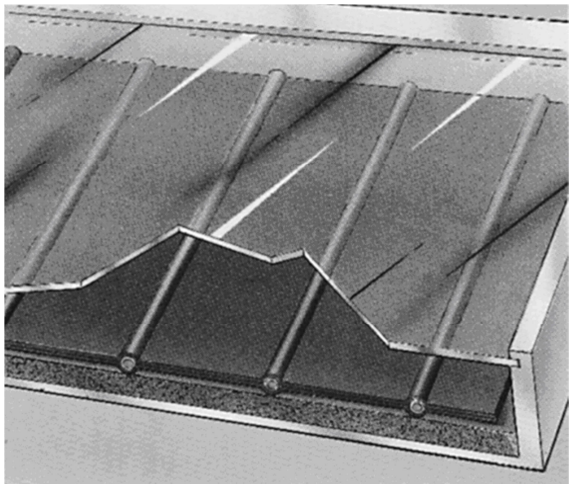


Figure 11: schematic drawing of a glazed flat-plate collector. The heat transfer fluid flows through the thin longitudinal pipes.

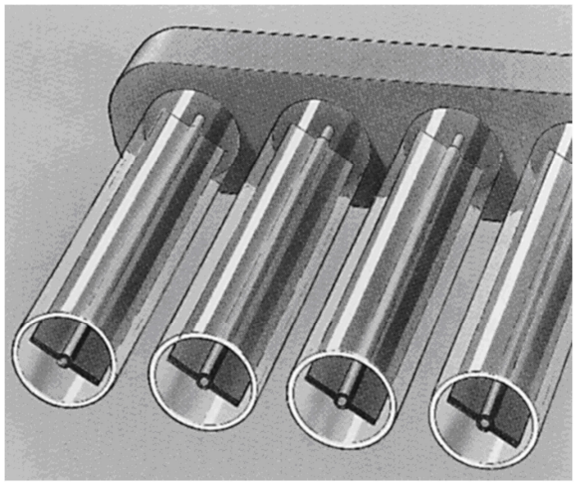


Figure 12: schematic drawing of a vacuum tube collector. The heat transfer fluid flows through the thin longitudinal pipes.

less than the surrounding ambient temperature, an efficiency could result even "greater than 100%". In this case the heat transfer fluid becomes heated not only by the sun, but also by the heat from the surrounding environment.

There are three different types of collectors. The most suitable one depends on user needs.

Unglazed collectors: uncovered flat-plate collector type. Unglazed collectors are ideal for heating pools and for certain uses of pre-heating hot water. In regions where strong winds prevail, there are greater convective losses. On the other hand unglazed collectors are low in cost and don't cause reflection (something which in glass–covered collectors often cause complaints).

Glass-covered flat-plate collectors (illustration on the left): are the most widely used collectors. They are suitable for pre-heating water, for the production of hot water and for space heating. They are a somewhat more expensive than uncovered collectors. Thanks to their good thermal insulation they are suitable for integration in facades.

(Vacuum) tube collectors (illustration on the right): are especially ideal for the production of hot water or where external temperatures are generally low (or when a considerable part of solar irradiation takes place in winter). This is based on the idea that the absorber in a vacuum tube only loses energy for thermal radiation. In addition, the reflective behaviour of light and the geometry of the tube in glass contributes to making the obliquely falling light arrive more efficiently to the absorber compared to what happens in flat-plate collectors. Overall, tube collectors are the most expensive though, and for certain uses are not always as suitable as flat-plate collectors.

Angle-dependent irradiation

Together with thermal properties, geometric and optical properties also contribute to establishing the efficiency of collectors. On one hand, in the presence of low angles of incidence (when the surface of the collector is irradiated "obliquely") the irradiated surfaces become smaller. On the other hand, the cover glass reflects light much more intensely the lower the angle of reflection. This property dependent on angle is called IAM (Incident Angle Modifier).

It is possible that the efficiency curve of a collector can be higher than that of another which due to its reflective properties shows a lower annual yield. As a consequence the IAM is equally important for the description of a collector as well as its efficiency.

In a flat-plate collector, depending on size, it is of little importance that the angle is traced on the longitudinal axis or the transversal axis (longitudinally or transversally), as long as the glass does not have an unusual structure or the collector is not too elongated in shape.

The physical phenomenon of reflection and partial shade is well understood. It can be described by means of the Ambrosetti function $K(\theta)=1-(\tan(\theta/2))^a$ with a single parameter. In respect to this reflectant properties are often defined at an angle of 50°. At this angle it is possible to experimentally define efficiency with great precision and evaluate the angular effect reasonably well. The IAM values between the longitudinal and transversal orientation are approximated with the function $K(\theta,\varphi) = K(\theta_l,0) * \cos^2(\varphi) + K(\theta_t,90°) * \sin^2(\varphi)$.

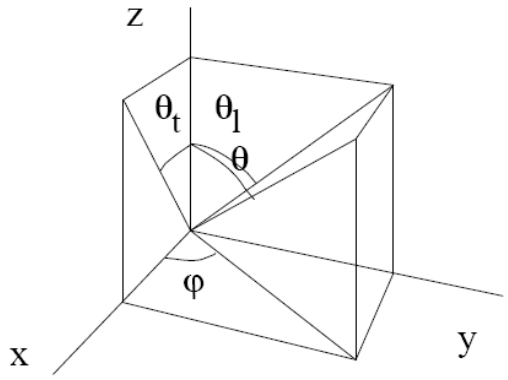


Figure 13: Definition of sphere coordinates

In tube collectors the two IAM values are different. Due to the reflective properties of the glass tube, in the transversal direction, the irradiation of energy diminishes less intensely in respect to what we should expect in the presence of the perspective reduction of the collector's surface. Beginning at a certain point though, the IAM drops drastically, due to the reciprocal shadowing of the tubes.

The longitudinal direction can also be calculated by the Ambrosetti function and with a point of measurement at 50° inclination from the norm. For the transverse direction, given the geometry of the collector, more measurement points are necessary and are interpolated with the help of a cubic spline. The conditions for the scope of the spline, (first and second derivation), are correspondent to a reflection on the axis Z θ=0°. All of the values between the longitudinal axis and transversal axis are approximated by the well-known McIntire function. However, there is also the possiblity to insert IAM tables obtained by measurement or simulation.

Collector efficiency according to European standards (EN)
The efficiency of a collector is represented by the so-called "efficiency curve". The difference in temperature (between the average collector temperature T_m and the outdoor temperature T_a) is divided by the total irradiated energy G_k:

$$x = (T_m - T_a)/G_k$$

A normal glass-covered flat-plate collector therefore has the following curve:

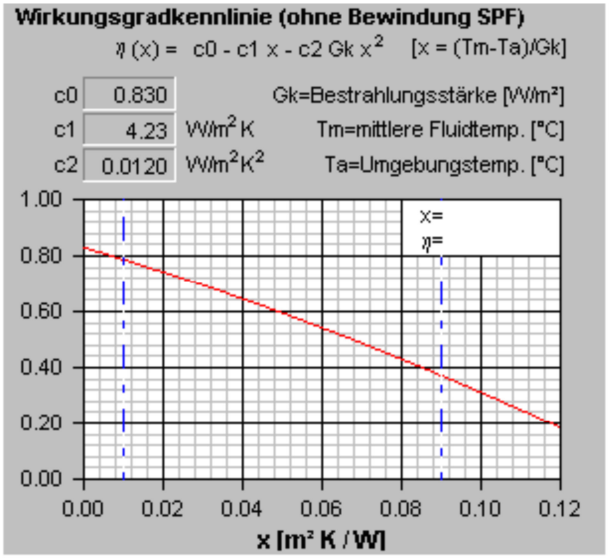


Figure 14: efficiency curve of a glass-covered flat-plate collector. The higher the temperature of the collector, the lower the efficiency. The intensity of irradiation is G_k = 800 W/m²

The trend of the curve can be described by means of a polynomial of the second order, clearly determined by means of three parameters, c_0, c_1 and c_2 (or by means of η_0, a_1, a_2; values measured at a wind velocity of 2-4 m/s):

$$\eta(x) = c_0 - c_1 \cdot x - c_2 \cdot G_k \cdot x^2$$

c_0 is the efficiency rate achieved when the average temperature of the collector and the outdoor temperature are equal. This value should be as high as possible. c_1 and c_2 are a combination of different loss factors. In a well insulated collector, these values should be as low as possible.

The operation of a solar energy system requires a certain compromise. On one hand you need a collector to work at the highest efficiency level, on the other the generated hot water should have a temperature of 50°-60°C. This means inevitably having the collector operate at these temperatures.

This explains why solar energy is often used for the pre-heating of water in large buildings. When cold water is heated from 10°C to 30°C, the collector works at a high level of efficiency. In terms of energy demand, it is of little importance that the water is heated from 10 to 30°C or from 30 to 50°C. Therefore the efficiency rate of collectors is quite high in pre-heating. These kinds of systems can be profitable already after a few years.

As briefly outlined, there are three main collector categories. They are distinguished among other specifications by their efficiency rate curves.

- Glass-covered flat-plate collectors: c_0 = 0,75 – 0.85, c_1 = 3-6 W/m²K
- Tube collectors: c_0 = 0.65 – 0.80, c_1 = 1 – 2 W/m²K
- Unglazed (uncovered) collectors: c_0 = 0.90 – 0.95, c_1 = 10 W/m²K

The illustration shows the most efficient models of these three types of collectors:

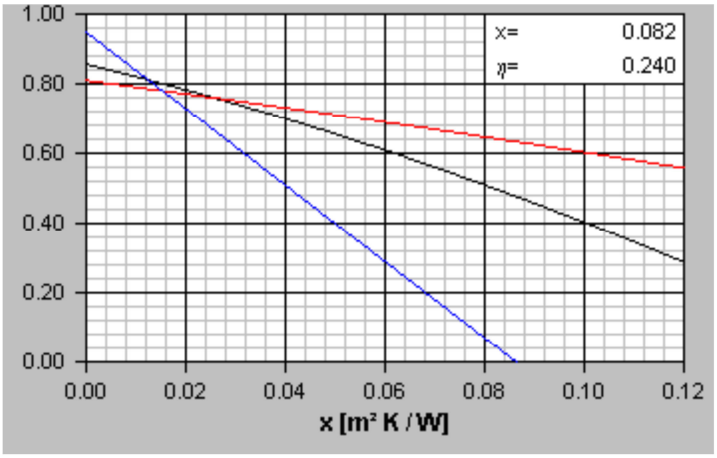


Figure 15: efficiency rate curve of different collector types: unglazed flat-plate collector (steepest curve), glass-covered flat-plate collector, tube collector (flat curve).

A value of $x = 0.10\ m^2\ K/W$ corresponds at an irradiance of 800 W/m^2 to a temperature difference of $T_m - T_a = 80°C$. At these operating conditions, the indicated tube collector still has an efficiency rate of 60%, the covered collector 40%, while the unglazed collector is no longer able to produce energy at these temperatures.

Numeric model for non-covered collectors

In accordance with the standards for measurement (EN 12975) non-covered collectors are given an additional parameter. The efficiency function curve has the following form:

$$\eta = \eta_0 * (1 - b_u * u) - \frac{(b_1 - b_2 * u) * (t_m - t_a)}{G''}$$

The coefficients η0, bu, b1 and b2 are calculated by means of the adaption of the curve. G" is the total irradiance which is determined on the basis of the following equation:

$$G'' = G_k + (\varepsilon / \alpha)(E_L - \sigma T_a^4)$$

EL is the measurement of the intensity of long–wave irradiance onto the collector area and Ta is the outdoor temperature. For ε/α the value is fixed at 0.85, if the supplier has not given other indications.

Input parameters

The decisive parameters that describe the efficiency of a collector, include in addition to the **absorber area** A, **efficiency rate parameters** c_0, c_1 and c_2 and the **IAM values** KCH1 and KCH2, the **specific heat capacity** of the collector. The latter measures the "thermal inertia" of the collector: if a collector has great heat capacity it lasts longer, up until a certain quantity of solar irradiation has heated up the collector. On the other hand the collector still passes heat to the fluid when the sun is covered by a cloud. A collector with little heat capacity reacts more quickly to the variations of irradiation intensity.

In many cases the orientation of the collector is established on the basis of the pitch and the orientation of the roof. Here one can ask if the collector should be oriented east or west (if south is not possible) or if it should be integrated into the facade. With flat roofs, orientation and tilt angle can be chosen freely. The question to ask in these cases is 'With which angle is it possible to obtain the maximum annual efficiency?' There is no single answer. The optimum orientation and tilt angle could be different according to water consumption, the size of the tank, the climate and many

other conditions.

For the choice of orientation, Polysun makes available the following dialogue window:

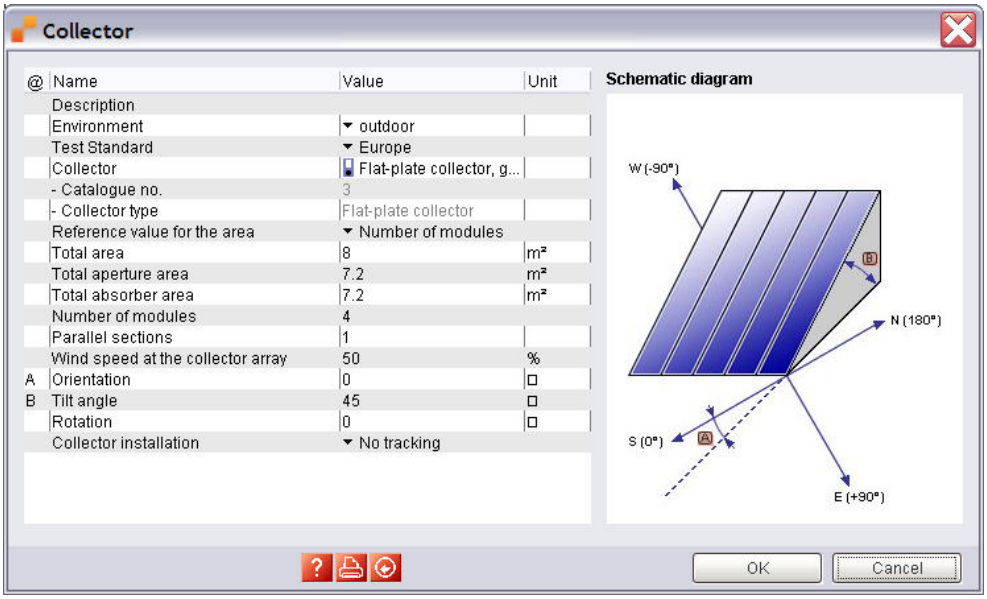


Figure 16: dialogue window for defining collector orientation. Tilt angle and orientation can be optimized for single months or for the entire year. Tube collectors can be arranged

Tracking

Tracking systems enable collectors to yield an increased heat output. The use of solar tracking systems can be more or less worthwhile depending on use and location. The closer to the equator and the larger the system and the more the use of tracking systems will be worth your while. As these locations can enjoy a higher annual irradiance start-up costs for tracking systems will be accordingly lower.

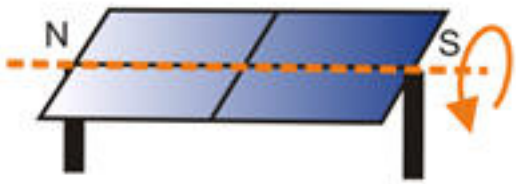
The collector characteristic dialogue box gives the user the opportunity to choose from three different types of tracking devices.

- One-axis azimuth tracker

  The tracker causes the collector to rotate about the vertical axis.

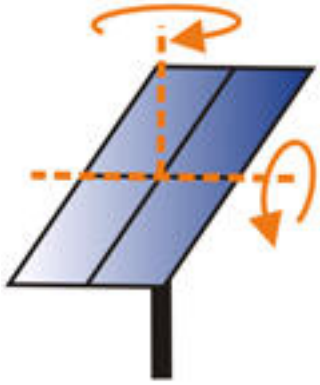
- One-axis zenith tracker

  The tracker causes the collector to rotate about the horizontal axis.



- Two-axis tracker

  The tracker causes the collector to rotate both about the horizontal and the vertical axis.



Simulations with sun-tracking collectors involve the calculation of computationally intensive IAM-factors. This heavily affects simulation times that may be considerably longer.

Collector data entry in Polysun according to European standards

Collector type:	Chapter 4.1 describes two different models to calculate the efficiency value of the collector. For the input “flat-plate or tube collector” the standard model will apply whilst for unglazed collectors the “uncovered collector” model will apply.
Eta0 laminar (1); bu:	"Eta0 laminar" is the efficiency value of a collector operating at outdoor temperature and in laminar flow conditions. Values of $Eta_{0\ laminar}$ up to and of a_2 refer to the aperture area of the collector and are determined at a radiation intensity of 800W/m^2. “bu” is the wind reduction coefficient for uncovered collectors.
Eta0 turbulent:	The efficiency value of a collector operating at outdoor temperature and in turbulent flow conditions.
A1 (without wind) (2); b1:	A1 coefficient for flat-plate and tube collectors measured with no wind or b1 in uncovered collector models.
A1 (with wind) ; b2:	A1 coefficient for flat-plate and tube collectors measured in normal ventilation conditions or b2 for uncovered collector models.
A2 ; epsilon/alpha (3):	A2 coefficient for flat-plate and tube collectors or epsilon/alpha or uncovered collector models.

Dynamic heating capacity (4):	Value computed pursuant to EN 12975-2, section 6.1.6.2
Nsis-Axis:	The orientation (tubes at a 90° horizontal or vertical elevation) for tube collectors. Mostly irrelevant in case of flat-plate collectors.
IAM model:	The "Ambrosetti Model" (described in chapter 1.3) is used to interpolate different flat-plate collectors. Tube collectors are interpolated by means of a cubic spline.
Angle factors (5):	IAM data are read over a table. Azimuth φ and elevation θ are described in chapter 1.3.
Volume:	Measured value of fluid volume in the collector including the manifold tubes.
Internal diameter:	Internal diameter of heat transfer pipes in the collector. C in figure n. 17.
Single pipe length (6):	The length of a single heat transfer pipe in the collector. A in figure n. 17.
Parallel piping:	Number of parallel pipings in the collector. 5 in figure n. 17.
Pipe roughness:	Roughness factor relating to the inner side.
Linear form factor:	The form factor of a pipe ranges based on bend radius between 1-1.5. The factor for rectilinear pipes is 1.
Friction factor:	The friction factor refers to pressure drops in branchings, valves, etc. If not measured it will be set on zero.
Test flow rate (7):	Fluid flow rate during a test. In l/h and collector.

(1): In the event that no indications are available about $Eta_{0\ laminar}$, $Eta_{0\ turbulent} = Eta_{0\ laminar}$ will apply.

(2): Pursuant to new provisions the $a_{1\ with\ wind}$ coefficient is detected at a wind speed of 3 m/s. The efficiency parameter c_1 may be worked out as follows:

$$c_1 = a_{1withoutwind} + \frac{(a_{1withwind} - a_{1withoutwind})}{(3\mathrm{m}/s)} * v_{wind} * windportion$$

If a $_{1\ without\ wind}$ is not expressly indicated, select a $_{1\ without\ wind}$ 10% lower than a $_{1\ with\ wind}$ for flat-plate collectors and 5% lower for tube collectors.

(3): Fix epsilon/alpha = 0.85 in case this was not otherwise pre-set by the manufacturer.

(4): Directive EN 12975-2 establishes two different procedures for the calculation of dynamic heat capacity; in appendix J3 a measured value and in section 6.1.2.1 a calculated value. The calculated value is typically much lower than the measured value. Collector geometry is not taken into consideration. Notwithstanding the high reliability of the measured value the calculated value is actually used in Polysun.

(5): Angle factor tables may not yet be entered directly by the user. In the creation of a given collector a collector with similar IAM values should be copied.

(6): In case no measurable or obvious indication is given enter the width or length of the absorber.

(7): Test flow rate, maximum flow rate, maximum pressure and maximum temperature do not currently affect the calculation.

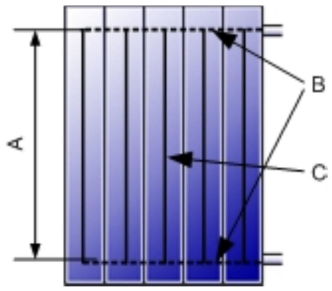


Figure 17: collector model (A: length of single pipe, B: manifold pipes, C: single pipe)

5.4.7 Collector model according to American standards (ASHRAE)

Collectors complying with the ASHRAE 96-1980 and 93-1986 standards are modelled analogously to collectors complying with European standards. An overview of the main differences is provided below.

The following applies to the efficiency:

$$\eta(x) = \eta_0 + a_1 \cdot \frac{P}{I} + a_2 \cdot \frac{P^2}{I}$$

where

$P = Ti - Ta$

Ti = temperature of the fluid flowing through the collector

Ta = ambient temperature

I = irradiance on collector surface

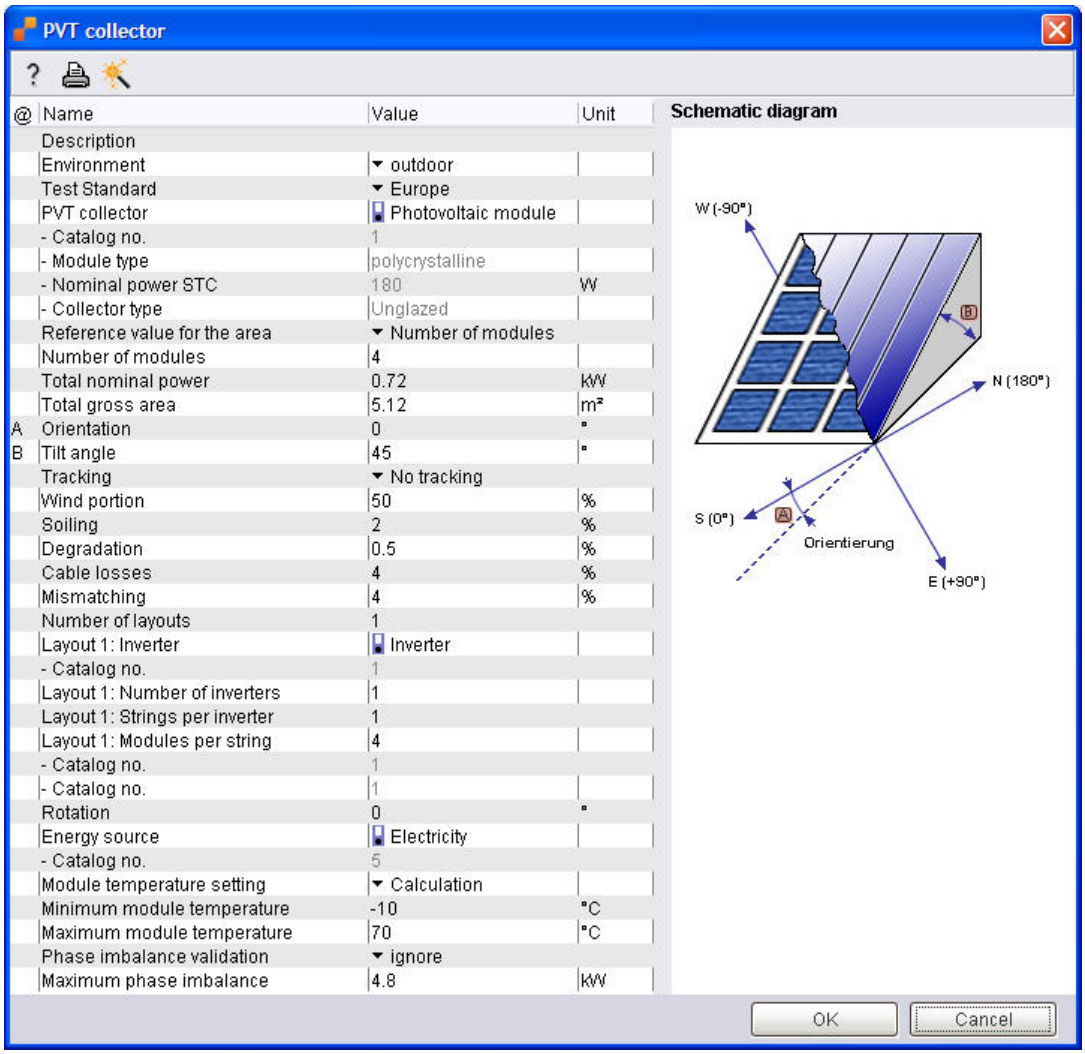
The values measured for η_0, a_1 and a_2 refer to the gross-surface. The relevant standard does not require absorber surface to be measured and so this is equalled to the aperture area. The a_1 value is recorded in the absence of wind; in case of wind blowing at 3m/s a_1 is to be multiplied by a 1.05 factor for tube collectors, 1.1 for glazed flat-plate collectors and 1.2 for unglazed flat-plate collectors. The influence that wind has on the collector is calculated like provided in the above chapter for European standards. Glazed and unglazed collectors can otherwise be calculated by means of the same model.

Should no indication be available for the mcp heat capacity the relevant field can be left blank; the standard value 10000 J/K will thus be used for the simulation .

The pressure loss can be deduced from three recorded interpolation nodes. Should no indication be available in this respect the relevant fields can be left blank; the following standard values will then be used for the simulation: 72, 180, 288 [l/h] for volume currents, 262, 885, 1784 [Pa] for pressure losses.

PVT collector

This type of collector consists of a combination of a solar-thermal collector and a PV module. Possible parameter alterations are identical to the components described in greater detail above. This combined-system only differs from the individual solutions in its operating features. For further details see the relevant chapter.



@	Name	Value	Unit
	Description		
	Environment	outdoor	
	Test Standard	Europe	
	PVT collector	Photovoltaic module	
	- Catalog no.	1	
	- Module type	polycrystalline	
	- Nominal power STC	180	W
	- Collector type	Unglazed	
	Reference value for the area	Number of modules	
	Number of modules	4	
	Total nominal power	0.72	kW
	Total gross area	5.12	m²
A	Orientation	0	°
B	Tilt angle	45	°
	Tracking	No tracking	
	Wind portion	50	%
	Soiling	2	%
	Degradation	0.5	%
	Cable losses	4	%
	Mismatching	4	%
	Number of layouts	1	
	Layout 1: Inverter	Inverter	
	- Catalog no.	1	
	Layout 1: Number of inverters	1	
	Layout 1: Strings per inverter	1	
	Layout 1: Modules per string	4	
	- Catalog no.	1	
	- Catalog no.	1	
	Rotation	0	°
	Energy source	Electricity	
	- Catalog no.	5	
	Module temperature setting	Calculation	
	Minimum module temperature	-10	°C
	Maximum module temperature	70	°C
	Phase imbalance validation	ignore	
	Maximum phase imbalance	4.8	kW

Figure 18: PVT collector dialogue box

5.4.1 Design wizard for membrane expansion vessels

Polysun enables users to design membrane expansion vessels according to EN 12828.
It is assumed that a system simulation has been completed. Then open the “Solar loop pump” dialogue box and click on the design wizard icon (in the upper portion of the box). The tool is intended for solar loops only.
Now, a new dialogue box opens prompting the user to enter various information. Hoovering with the mouse over an input field, a help text is shown explaining the meaning of the relevant entry. All values shown as “derived values” are directly imported from the Polysun simulation and are essentially based on pipe size, collectors and controller settings. All derived values must be checked for plausibility.
Click on the “Import” button to import all modified values. All changes in the “Solar loop pump” dialogue box must be confirmed by pressing “OK”. Now, you can make other changes and start the simulation. The dimensioning of membrane expansion vessels does not affect the simulation and its results. The values calculated for the membrane expansion vessel are, then, displayed in the professional report under the section

dedicated to the relevant pump.

Calculation basis for membrane expansion vessels in Polysun

Minimum operating pressure (p_0): $p_0 = p_{st} + d_{pp} + d_p$

Final pressure (p_e): $p_e = p_{SV} - 0.5bar$ for $p_{SV} \leq 5$ bar

$p_e = p_{SV} - 0.1bar$ for $p_{SV} > 5$ bar

Nominal capacity (V_n): $V_n = (V_e + V_V + V_k) * \frac{p_e+1}{p_e-p_0}$ where:

Collector capacity (V_k): Calculation through Polysun

Expansion volume (V_e): $V_e = \frac{n}{100} * V_A$ where:

Degree of expansion (n): depending on the fluid in the loop

System volume (V_A):

$V_A =$

$\sum Kollektorvolumen, Rohrleitungen\ etc.$collector volume, pipes, etc.

Water header (V_V): $V_V = 0.005 * V_A$ for $V_n > 15$ l with $V_V \geq 3$ l

$V_V = 0.2 * V_A$ for $V_n \leq 15$ l

5.4 Heat pumps and geothermal components

5.4.8 Heat pump catalogue entries with reference points from a file

In the air-water heat pump catalogue as well as in the water-water heat pump catalogue catalogue there are two ways in which you can define the reference data for the heat pump. The first is to insert the reference points directly into the appropriate fields of the catalogue (e.g. ”Heating power at A20W35“, ”Electrical power at A20W35“). Alternatively the reference data can be read from a file by inserting the name of the reference file in the column „File name“. The file must be saved in the Polysun folder” profiles“ (with Windows 7 the standard path is „C:\Users\Public\Polysun\profiles“). The file is saved in ”csv“ format and is structured as follows (in Windows 7 the default path is ”C:\Users\Public\Polysun\profiles“). The file is in “csv“ format. File formats vary depending on the type of heat pump and are specified in the respective sub-chapters.

The file data substitute the data in the columns „Heating power at XX“ and „Electrical power at XX“ and will no longer need to be defined. The other columns will have to be filled in, particularly „DeltaT at A7/W35“.

Within the file you may indicate reference points for any evaporator and condenser temperature.

5.5.2 Air-to-water heat pump

The air-to-water heat pump is depicted in Polysun as a component equipped with two hydraulic connections. The model is based on the input values Heating power and Power consumption; such

values were measured according to test standards EN 255 or EN 14511 on predefined sampling points (e.g. A2/W35). The electrical power absorbed by the heat-pump is calculated by linear interpolation of the sampling points. The thermal heating power is defined by linear interpolation of the corresponding quality grade of the sampling points.

Frosting and de-frosting behaviour are likewise taken into account through the norm and may be thus simulated in Polysun. This model only applies to intermittent heat pumps; variable-speed heat pumps are described in the chapter 5.5.3 “Modulating air-to-water heat pump”.

The results “Energy from/to system“ and “End Energy“ include the power of the heat pump and that of the internal heating element, in case the auxiliary heating was switched on. To calculate the COP (Coefficient of Performance), the power of the internal heating element is, however, to be deducted from the results. The result “COP“, therefore, only applies to the compressor and not to the heating pump as a whole.
The absorbed power of compressor, internal circulation pump, fan as well as the supplied heat output are taken into account in the COP calculation.

Within a hydraulic scheme you will be able to switch from a boiler to a heat-pump by accordingly setting the selection of the heat generator.

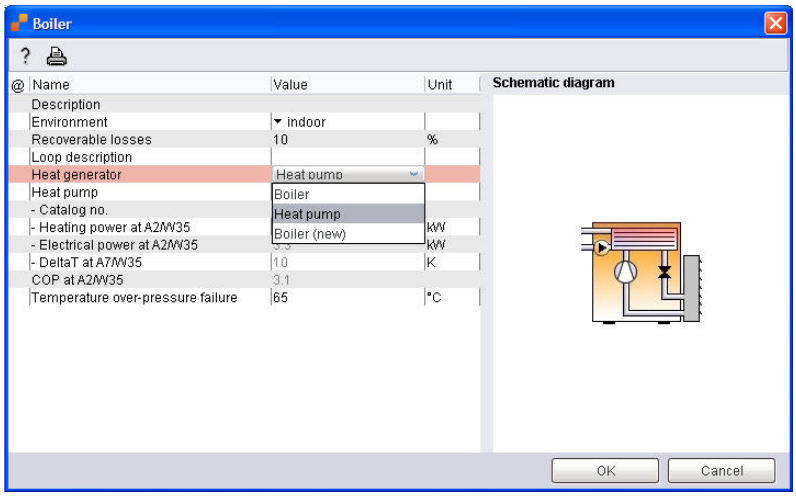


Figure 19: selection of air-to-water heat pump

The heat-pump-specific operating times may be defined by means of the minimum operation times and minimum idle period that may found in the heating controller.

Q is implemented from the measured values; this requires Tv. This is approximated through T_U = Q’/k * V – T_i (1) where k = Q_{ref} / V_{ref} * 1/DeltaT_{ref} (2) and Q’ from the previous time-step or on switching on the heat-pump Q’ = Q_{ref}. This allows Polysun to calculate with Q’, V, T_i the outflow temperature.

All calculations are carried out with delta T_{ref}.

As a result: the calculation enables a correct calculation also for arbitrarily selected v.

Exceptions: for (1) and (2): the internal heat-exchanger is capable of transferring the overall power. The formulism will become inaccurate for V << V_{ref}.

5.4.8.1 Catalogue entries with reference points from a file

The file format for the definition of reference points in a profile file is as follows:

```
#Heat pump name;;;;
#Evaporator[°C];Condenser[°C];Heating power[W];Electrical power [W]
20;35;20800;4100
10;35;18700;4100
…
…
```

5.4.3 Modulating air-water heat pump

The modulating air-water heat pump is integrated in Polysun as an extension to the air-water heat pump. Its working principle very closely follows the air-water heat pump model. Save as otherwise defined, the information provided for the air-water heat pump model also applies to the modulating air-water heat pump. Below is an overview of the different types of modulation available in Polysun (the type of modulation is available as a field in the air-water heat pump catalogue):

Modulation	
None	Non-modulating heat pump, see chapter 5.5.2.
Based on outdoor temperature	A heat pump that adjusts its power level based on outdoor temperature so that the thermal power output remains constant over time. This kind of heat pump can be simulated with the model for basic air-water heat pumps (see chapter 5.5.2). In the process, reference points are entered whose modulation has already been taken into account, i.e. the thermal power is identical for all reference points, whilst the electrical power consumption varies.
Based on demand	The modulation takes place steplessly based on the desired thermal power output. For more details see the following sub-section.
Two-stage	The modulation takes place in two steps based on the desired thermal power output.

Different modes of operation can be set for on-demand and two-stage controlled heat pumps via the controller. All modes of operation are subordinated to the heat pump's "Status" controller value. If the latter is set to "0", the heat pump will be switched off in any case, regardless of the mode of operation. If the status is set to "1", the heat pump will at least run, in any case, at the lowest power level. In this way, the heat pump will not switch off if, for example, while running in the "Defined power level" operating mode a "0" is forwarded to it through "Desired power level". The heat pump must be switched off by through its status.

Should the mode of operation need to be controlled, the "Heat pump: status" should be set as an output in the programmable controller. For each operating status, a numerical value corresponding to a given mode of operation should be assigned to this output. In the following chart, these numerical values are shown in the "Controller value" column.
Based on the respective mode of operation, additional information should be provided to the heat pump. Such information is to be entered via an additional output in the controller. Subsequently, for each operating status the controller will need to have been allocated by these additional outputs a value which, however, will only be taken into account if the mode of operation is appropriately set. The following chart lists the possible modes of operation.

Description	**Controller value**	**Additional controller outputs**	**Function description**
Fixed maximum	0	-	The heat pump runs at the

power			maximum power level
Heat-driven operation mode	1	„Controlled power heat generator“	The heat pump delivers, as far as possible, the desired thermal power set via the “Controlled power heat generator“ controller value. (default mode)
Power-driven operation mode	2	“Controlled power heat generator“	The heat pump draws, as far as possible, the available electrical power set via the “Controlled power heat generator“ controller value.
Defined power level	3	“Controlled power level“	The heat pump is run at the power level closest to the “Desired Power Level“.

In the event that the additional controller output is not configured in the mode of operation 1, 2 or 3, the heat pump will be run at the maximum power level.

In the event that the mode of operation is not set through the controller, the heat pump will be run in the “Heat-driven“ operation mode as a standard.

In the event that the heat pump selected from the catalogue does not provide any selectable power controller (field ”Modulating“), the controller values shown in the above chart will not be taken into account. In this case, “Controller mode“, “Controlled power heat generator“ and “Controlled power level“ may not be selected in the controller configuration menu.

In the typical case of power control being heat-driven, two configuration options are made available to the user. Two options are provided for setting the controller parameter. Similarly to the boiler model, the heat generator controller may be set to a constant inlet temperature for tank loading purposes. In so doing, the “control mode“ is implicitly set to “Heat-driven”. The controller in/outputs are set to the same settings as for a modulating boiler.
More complex control settings are performed through a programmable controller, whereby, with the aid of the HEATING CURVE function, i.e. by means of the heating curve, the current inlet temperature required for the heating loop and, as a result, with the aid of the MATCHFLOW function, also the required thermal power output are calculated. The desired thermal power output is then transferred to “Controlled power heat generator” via a controller output. When dealing with similarly controlled systems, special attention should be paid that heat pump size and the parameters of the HEATING CURVE function (for a more accurate description see the ”Programmable controller“ chapter) are appropriately matched to the building to be heated and its location. In the worst-case scenario, should the heating curve not be appropriately configured, the heat pump will modulate to too low a power level and will be unable to match the energy demand as a result. If, on the contrary, the curve is set so that the heat pump constantly delivers more energy than required, instead of running non-stop at a lower power level and with a higher efficiency, this reverts back to the on-off operation. In this case, the potential of the power controller are not fully exploited.
In the event that the heat pump is also used for DHW preparation purposes, it should be ideally run at reduced power for this purpose. The “Defined power level“ operating mode may be used to this end.

5.4.3.2 Stepless modulating Air/Water-Heat pump

The model for stepless modulating air/water heat pumps was developed within the framework of the “Implementierung der leistungsgeregelten Luft/Wasser-Wärmepumpen aus dem BFE-Projekt „Effiziente Air/Water-Heat pumps durch kontinuierliche Leistungsregelung“ in der Simulationssoftware Polysun“ [Implementation of power-controlled air/water heat pumps from the BFE-Project “Efficient air/water heat pumps through continuous power control” in the Polysun simulation software”].

Similarly to the other heat pump models available in Polysun, the model for stepless modulating air/water heat pumps too is based on an interpolation procedure. The family of curves is described by means of a number of measuring points that are saved in a text file. Reference points must be necessarily saved as a profile file. The format is:

```
#Heat pump name;;;;
#Power level[0-1];Evaporator[°C];Condenser[°C];Heating power[W];Electrical power[W]
1;-20;30;5313;2310
1;-12;30;6745;2448.7
1;-2;30;8739;2553.3…
…
…
0.5;-20;50;2520;1602.034329
0.5;-12;50;3158.1;1683.788578
0.5;-2;50;3989.74;1687.274583
```

where “Evaporator“ corresponds to the outdoor temperature and ”Condenser“ to the inlet temperature. This input format makes it possible to process data in a clear, intelligible way using a spreadsheet program such as Microsoft Excel.

For results to be fairly accurate, a total of at least 140 reference points should be defined covering the expected operating range. For the simulation of home systems, reference points should be ideally spread out over an outdoor temperature range from -20°C to +20°C (= evaporator temperature) and an inlet temperature range from 30°C to 60°C (= condenser temperature). However, there is also a chance that in a given time step an operating point is needed for the simulation that lies outside the temperature range defined in the file. In this case, the data curve will programmatically flatten out, as is shown in the following chart in the form of dashed lines.

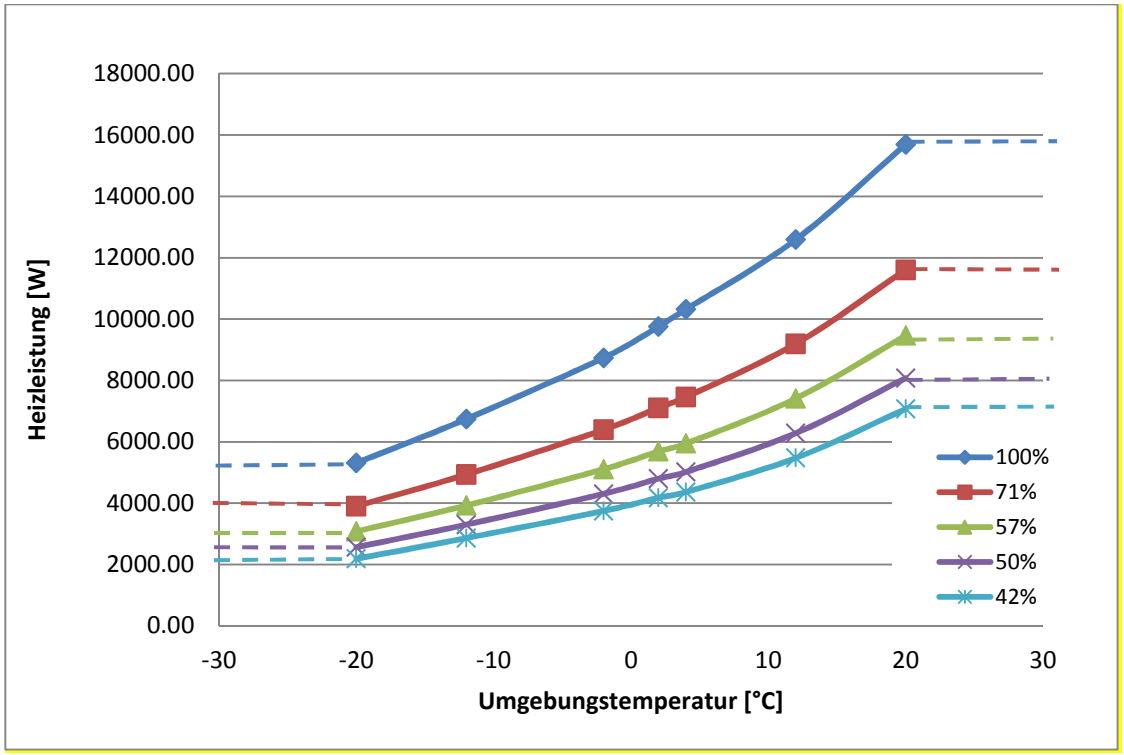


Chart: Outdoor-temperature heating-power data for different power levels. The dashed lines show the programmatic extension of data series.

The simulation requires that the electrical power absorbed by the heat pump as well as the thermal power output are calculated for each time step.
In the heat-driven operation mode, i.e. in the standard case, the required thermal power is calculated by a controller, see chapter 5.5.3 Modulating air-water heat pump. The power is then transferred to the “Controlled power heat generator“ of the Heat pump component via a controller output. Polysun provides the outdoor temperature for each time step. The last required input parameter is the inlet temperature at which the heat pump is currently operating. However, as this is only calculated when the system is simulated, the inlet temperature is extrapolated from the data collected in the latest time steps (similarly as for the non-modulating air/water heat pump model). In a first step, using the known input parameters and the defined reference points, the power level is calculated by means of scattered data interpolation. If this turns out to be lower than the lowest power level specified in the reference points, it will be rounded off to the lowest power level. Then, in a second step, the current thermal power output and the currently absorbed electrical power are interpolated for the calculated power level and passed on to the overall system simulation.

The power-driven operation mode runs in a way that is very similar to the heat-driven mode. For the determination of the power level, however, the electrical power consumption together with the outdoor and inlet temperature are used as interpolation points instead of the required thermal power.
If the required power level is sent directly by the controller, the interpolation step will no longer be required for the determination of the power level.

Schemes with and without DHW preparation respectively for a new building and an old renovated building are presented as an example in the scheme catalogue under “Swiss Systems“. As has been mentioned, the parameters for the HEATING CURVE function need to be adjusted in the programmable controller. In the template, these parameters are set to the configured building and

to the location Rapperswil SG.

5.4.3.3 Two-stage air/water heat pump

The two-stage heat pump model is implemented as an extension to the standard air/water and water/water heat pump model. In this model, the two-stage heat pump is presented as a device containing two units operating in parallel. For the pump to run at full power, both units need to be activated. If the power is reduced to 50%, only one unit is required to be running.
The heating power delivered at the current operating point is calculated by means of the existing model. The power is then reduced to 50% by decreasing both the heating power and the electrical power by 50%.
In the heat-driven operation mode, a check is made whether 50% of the power is sufficient to meet the required power demand. If this is the case, the heat pump is run at 50% of its capacity.
In the power-driven operation mode, the power is reduced to 50% as soon as the available electrical power drops below 90% of the electrical power absorbed by the heat pump when running at 100% capacity.
In the “Fixed power level“ operation mode, the power is reduced to 50% if the required power level is equal or lower than 50%.
In the database or in the profile file, reference points are entered for the full power; the format is the same as for a standard air/water heat pump.

5.4.4 Water-to-water heat pump

A water-to-water or brine-to-water heat pump is a component fitted with four hydraulic connections. The calculations of heating power and absorbed power are based on a so-called “Scattered data interpolation“. This also enables unknown interpolation nodes to be omitted, which may result in less accurate results. As with air/water heat pumps start-up losses will not be considered for water/water heat pumps either. Besides the supplied amount of energy the calculated coefficient of performance takes into account only the amount of energy absorbed by the compressor.
When configuring a system care should always be taken to ensure that brine temperature at the heat-pump input (T_s) is always lower that the inlet temperature (T_v) in the heating loop.

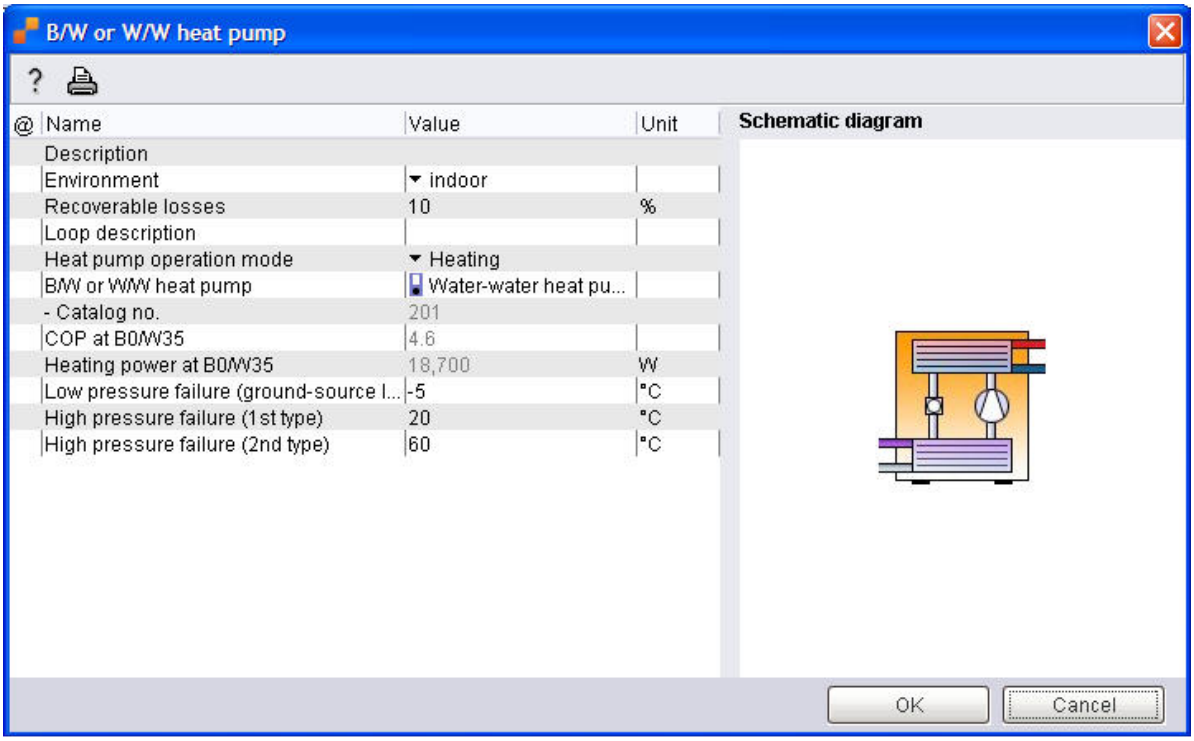


Figure 20: water-to-water heat pump

A realistic heat pump control can be reproduced by means of the minimum operation time and the minimum idle time.

5.4.4.1 Catalogue data with reference points from a file

The data format for the definition of reference points in a profile file is as follows:

```
#Name der Heat pump;;;;
#Evaporator[°C];Condenser[°C];Heating power[W];Electrical power[W]; Cooling
power[W]
-5;35;14800;3700;0
0;35;17200;3600;0…
…
…
```

Optionally, the cooling power may be also indicated. Where this is greater than 0, the internal losses of the heat pump will be taken into consideration in the simulation.

$$\text{Internal losses HP} = \text{cooling power} + \text{electrical power} - \text{heating power}$$

5.4.4.2 Two-stage water/water heat pump

A two-stage water/water heat pump works on the same principle as a two-stage air/water heat pump (see *Two-stage air/water heat pump*). Its operation is based on the standard water/water heat pump model.
Two-stage operation is only considered in case of heating.
In the database or in the profile file, reference points are entered for the full power; the format is the same as for a standard water/water heat pump.

5.4.5 Ground-source loop

Depending on output requirements and local conditions a ground-source loop can reach a depth in the range of 50 to over 100 metres. Three different types of ground-source loops (single-U, double-U and coaxial) are typically lowered into the borehole. The mathematical model that Polysun uses for ground-source loops was imported from the EWS programme.
Compatibility with the EWS programme makes it possible from user level Designer and above to enter EWS project files directly into Polysun. The strong model running in the background makes it likewise possible to set-up ground-source loop fields. These are characterised by indicating Eskilson's g function:

$$g = (r,t)\frac{\Delta T_{Erde}(r,t)2\pi\lambda_{Erde}}{\dot{q}}$$

ΔT_{Erde} : *Temperaturabsenkung*

λ_{Erde} : *Wärmeleitfähigkeit*

$\dot{q}$: *spezifische Entzugsleistung*

This dimension-free step response reproduces the temperature behaviour within the ground-source loop environment with respect to the uninfluenced ground. Care should be taken that the g-function always only applies to a determined ratio between loop depth H and loop distance B. A wide range of ground-source loop arrangements is available in a separate catalogue. The B/H ratio does not necessarily have to match the actual arrangement as an effective B/H ratio will be extrapolated in case of any deviations. So as to keep extrapolation inaccuracies to a minimum the closest possible ratio should always be used.
The model admits a maximum of up to 10 different earth layers each of which will affect the calculation of the ground-source loop as a whole. Multiple temperature nodes will be calculated for each earth layer according to a detailed physical model. The model also takes into account a possible energy rear feed, for example, for regeneration or free-cooling purposes.
To effectively simulate the degradation of the loop a "Annual withdrawn energy" and a "Loop pre-load time" may also be entered. In doing so the ground-source loop will be preloaded with a constant load over the given length of time. Should the ground-source loop behaviour be calculated in the long term, preliminary simulation duration may be appropriately set (in menu under *Variant – Preliminary simulation*). This preliminary simulation enables the whole of the system to be simulated so that the actually arising workload may be applied to the ground-source loop. If 50 years are to be simulated the value to be entered is 17885 (49 * 365), i.e. 49 years are pre-simulated before the standard annual simulation is carried out.
Soil heating defines the difference between the average annual temperature of air and soil surface. Typical values are as follows:

- Forest, shady location: 0 K
- Field, meadow: 0.8 K
- Average value: 1.5 K
- Urban location up to 2 K
- Snow-covered elevation: up to 4 K

The axial temperature gradient defines temperature increase with depth. Such gradient is defined as the soil's geothermal heat flow/heat conductance. A typical value is 0.03K/m (0.06W/m^2 / 2 W/mK).

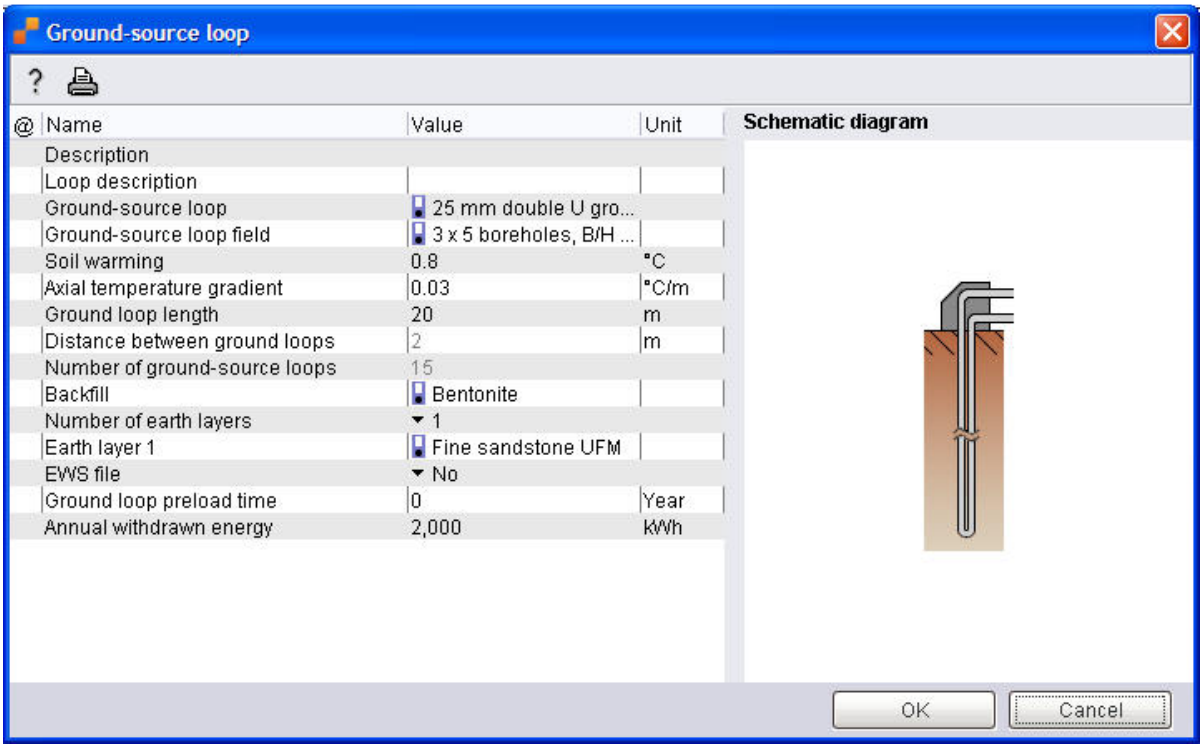


Figure 21: Ground-source loop

During the simulation Polysun calls up the relevant ground-source loop algorithm each 4 minutes producing thus consistently reliable end results.

For a detailed description of a ground-source loop see the publication issued by Hetag AG in 1997: http://www.bfe.admin.ch/php/modules/enet/streamfile.php?file=000000005132.pdf&name=000000195115.pdf

5.4.6 Ground-water loop

The software allows for a ground-water loop to be used in association with a heat pump. Here temperature is calculated depending on depth. The following assumptions were made in this respect:

For the northern hemisphere, soil temperature θ (x,t) depending on depth x (into the soil) [m] and time t [s] varies under the influence of the seasonal course of the outdoor temperature according to the following formula:

$$\theta(x,t) = \theta_m - \theta_0 \cdot \exp\left(-x \cdot \sqrt{\frac{\pi}{a \cdot T}}\right) \cdot \cos\left(\frac{2\pi}{T} t - x \cdot \sqrt{\frac{\pi}{a \cdot T}}\right)$$

where θ_m is the average outdoor temperature in °C, θ_0 is the maximum seasonal variation from the average outdoor temperature in °C, T is the number of seconds in a year and a is the thermal conductivity of the soil $\left[\frac{Wm^2}{J}\right]$.

For the southern hemisphere, soil temperature θ (x,t) depending on depth x (into the soil) [m] and time t [s] varies under the influence of the seasonal course of the outdoor temperature according to the following formula:

$$\theta(x,t) = \theta_m + \theta_0 \cdot exp\left(-x\sqrt{\frac{\pi}{a \cdot T}}\right) \cdot \cos\left(\frac{2\pi}{T} t - x \cdot \sqrt{\frac{\pi}{a \cdot T}}\right)$$

With a ground water depth of about 10-15 m and deeper it can be assumed with good accuracy that the ground water temperature remains constant over the year and matches the average annual outdoor temperature.

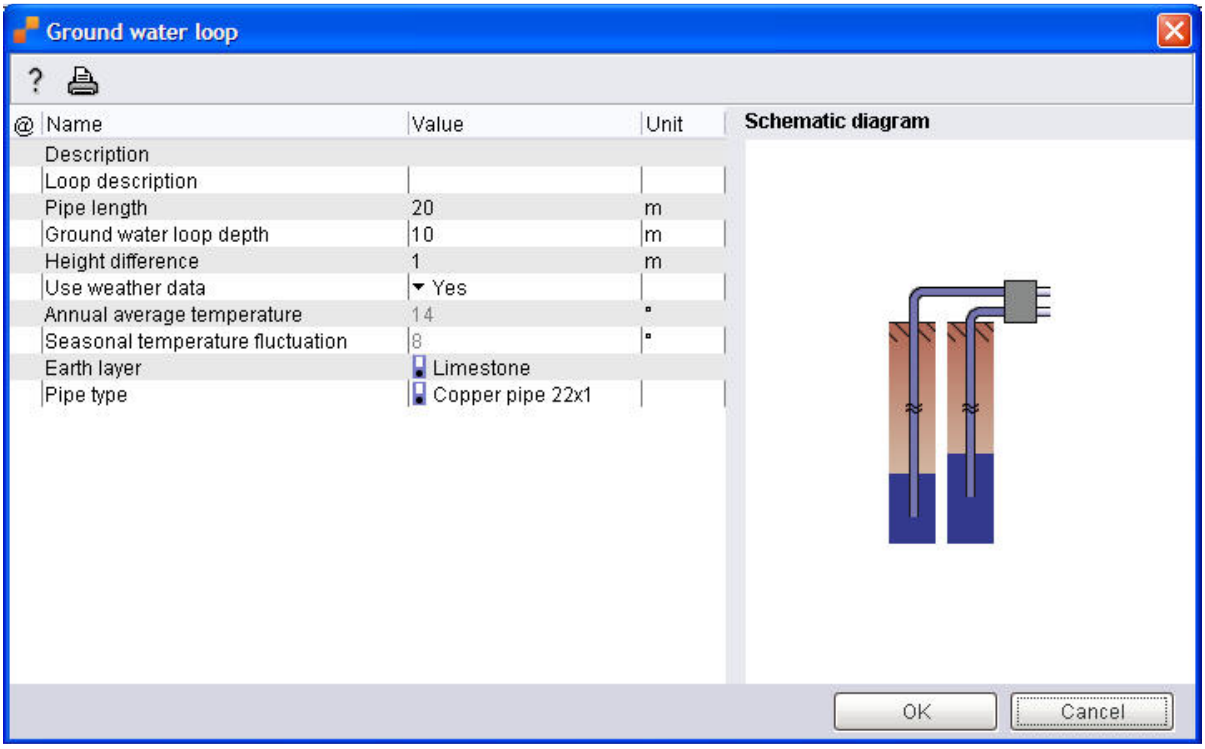
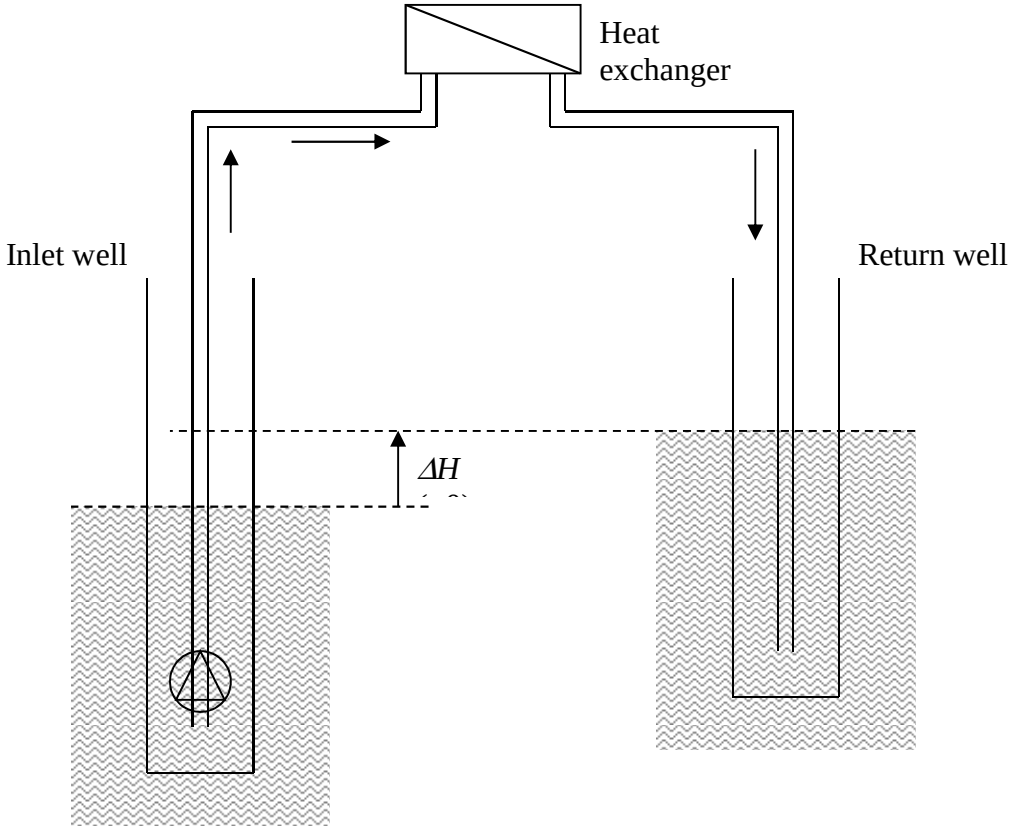


Figure 22: Ground-water loop

Static pressure

Polysun enables users to correctly calculate both static and dynamic pressure. To correctly calculate the required height difference ΔH a distinction should be made whether or not the loop return line is immersed in the return water tank. A negative difference is also possible; this will result in the pump being relieved of pressure. The image below illustrates this correlation:



5.5 General components of a heating loop

Below we provide an overview of the components that the software makes available for each thermal simulation regardless of the user level.

5.6.1 Cold water

The temperature of the cold water flowing through the system can be defined in two different ways. On the one hand, Polysun provides an algorithm allowing the temperature to be calculated over the year; on the other hand, the temperature can be exactly determined by means of a catalogue entry.
In this calculation, the water temperature, based on a ground-water model, is an approximation of the actual cold water temperature at a given place. To prevent water from freezing the minimum input temperature is set to 1 degree.

5.5.2 Hot water tanks

5.5.2.1 Tank types

With the aim of having an efficient system, in addition to the collector the thermal tank is of great importance. The choice of tank is decisive, from the moment that energy from the sun is not available and that occasional meteorological conditions occur for which the collector, for one or two days does not supply thermal energy. Three categories may be identified:

- Domestic hot water tanks (dimensions: twice the daily demand = 80-100 l per person)
- Tanks for hot water and space heating (dimensions: 100 l per MWh of heating demand)
- Seasonal tanks as tanks for several months (water storage tank, terrestrial seasonal thermal accumulator, etc.)

An average single family house with four people calls for tank dimensions of 300-500 l (domestic hot water only), 800-1500 l (with space heating) and over 30,000 l (seasonal tank). Combined forms also exist, in which the domestic hot water tank is integrated in a larger tank (the so-called combined tank).

5.5.2.2 Physical aspects in the optimization of the hot water tank

The quantity of energy *Q [J]* necessary for a heat transfer fluid of the mass *m [kg]* with a heat capacity c_p *[J/kg/K]* to heat a temperature ΔT *[K]* is calculated as:

$$Q = m * c_p * \Delta T$$

Nevertheless the distribution of heat in the tank is to be taken into consideration: normally the water is stratified at different temperatures. At the top, where the hot water is withdrawn, the layer with the hottest water is found (less dense water) and at the bottom there is the coldest layer (denser water). This stratification is desirable and for this reason the generation of the least possible turbulence is sought during the transfer of heat to the tank and the withdrawal of water.

Defining the dimensions of a tank is an exercise in proportion, in which various contrasting aspects are weighed out:

- A large tank has a great capacity
- A large tank needs a lot of energy to be “charged up”
- The higher the temperature, the greater the quantity of stored energy.
- The higher the temperature, the greater the tank losses

Usually it is sought to keep ready the quantity of water for daily consumption at the right temperature (or a few degrees higher) and to keep the rest of the tank temperature lower. This way the (cover of) hot water is always guaranteed and the losses from the tank are minimal. In the summer season though the tank can become overcharged, but having sufficient quantities of solar energy at this time allows acceptance of higher tank losses. The interesting fact is that the demand can be covered even in periods of bad weather. Since the water tank can be heated up to 95°C (also to 100°C) and the water reaches the desired temperature only when it is withdrawn and mixed with cold water, one can continue for several days.

5.5.2.3 Sizing the combined tank

The combined tank is used when one wants to produce domestic hot water and space heating from

a single solar energy system. Since the heating circuit and that of drinking water should not be united for hygienic reasons, the domestic hot water boiler tank is integrated into the main tank with the combined hot water tank. This has three main advantages:

- The surface area of the tank can be kept small (only the surfaces of the main tank), in this way heat losses are minimal.
- The domestic hot water tank, which normally requires higher temperatures than the space heating tank, can be placed in the warmer upper part of the main tank.
- A higher consumption of hot water doesn't cause turbulence in the main tank. This way the stratification is better maintained.

The principal of a combined tank resembles that of a continuous flow heater. The domestic hot water, in a system of separate pipes, passes through the main tank where it is heated. Because this heat exchange needs to be as efficient as possible, the interior tank should have thin walls and be made of a material with high thermal conductivity.

The internal tank is located preferably in the upper half of the main tank (5-10 cm below the top cover). Its size should correspond to approximately double that of daily consumption.

The heat losses at the connections (see following paragraph) can be indicated in the second part of the dialogue window. The values proposed by Polysun are equivalent to well insulated s-bending connections.

With the Polysun Designer one can create a new tank with a great variety of possibilities.

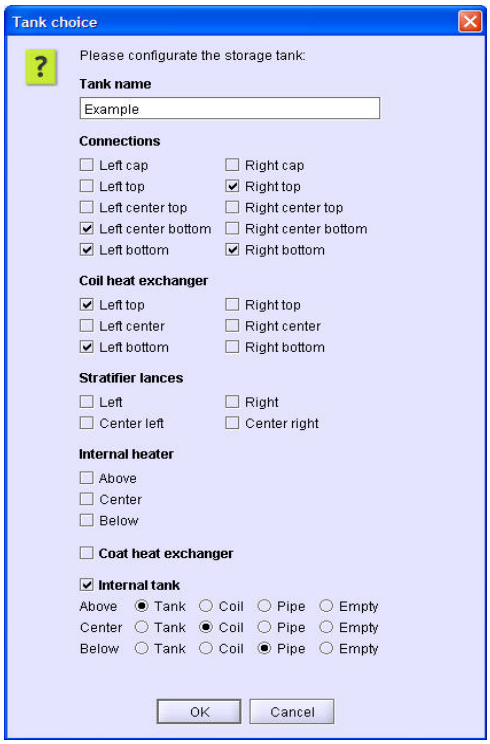


Figure 23: selection for defining a new tank.

With the selection of a new tank a new catalogue entry is created. In creating a new tank the standard components for the internal elements are established (coil heat exchanger, stratifier lances, auxiliary heating, etc.) The choice of internal elements are set in the tank catalogue, where it is possible to eventually create new specifications in the catalogue for the internal elements.

The following figure shows by example the possibility of choices (arbitrary denomination of tanks

by means of the letters of the alphabet):

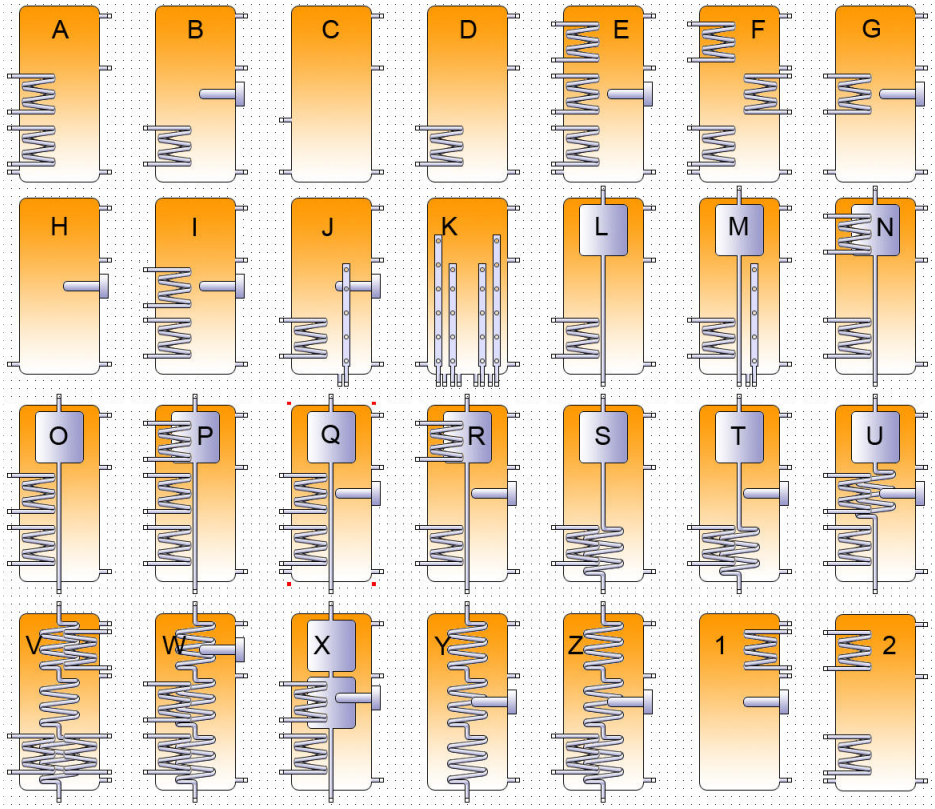


Figure 24: various tanks

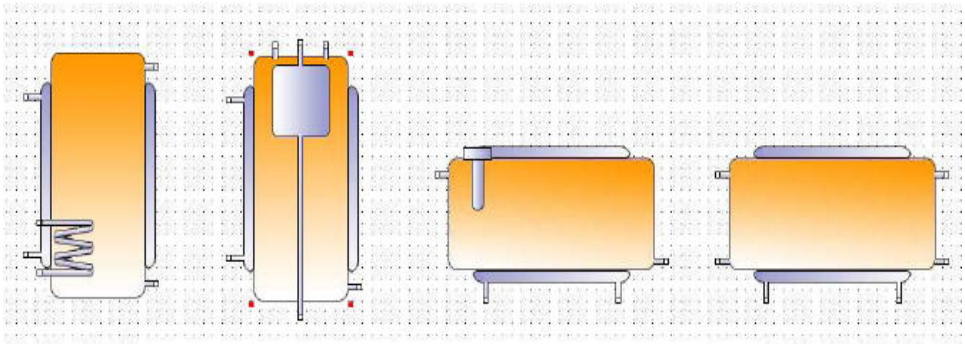


Figure 25: tanks with coat heat exchangers

5.5.2.4 Tank model and relative dimensions

For measurement, the height of the cylindrical part of the storage tank, the bulge height and the volume are important. By means of these three values the diameter is obtained. With the height of the tank we don't mean the total height, including the thermal insulation, but only that of the cylinder.

The interior of the tank is subdivided into twelve isothermal layers. The fluid contained by the bulge is always added to the lower and higher layer, for which the relative volumes are greater in respect to those layers from two to eleven. For the difference in density, the hot layers spread towards the top, the cold ones towards the bottom. In the border area there is heat transmission by means of conduction. A convective mix is ignored.

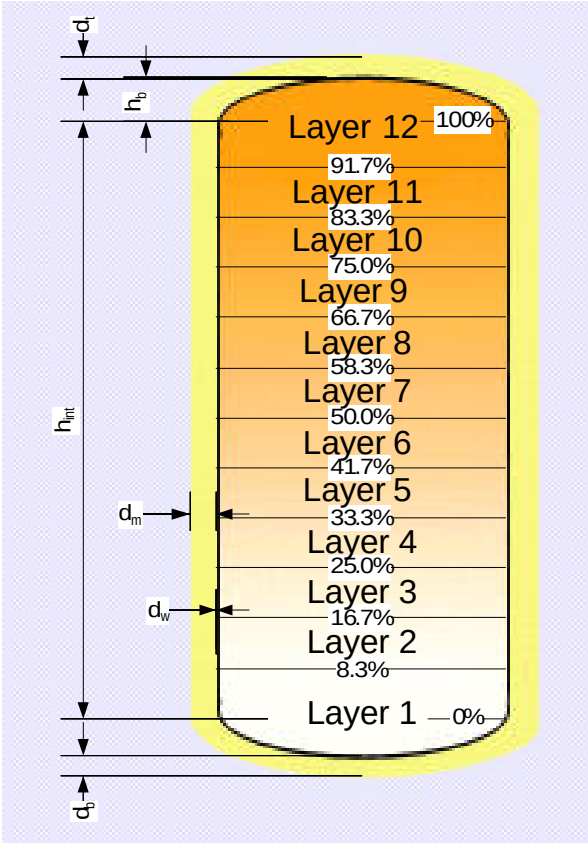


Figure 26: measures and tank layers (d_m = thickness of insulation, d_t = thickness of insulation at the top of the tank, d_b = thickness of insulation at the bottom of the tank, d_w = thickness of the walls, h_{int} = height, h_b = bulge height)

The internal components of the tank shown are not correctly positioned from a graphic point of view. The determinant indications regarding the positioning are those in percentage in the tank catalogue.

A tank has a maximum of ten connecting pieces available. The positioning in percentage is always measured from the lower part of the cylinder. (Note: not from the bottom of the tank). Likewise the connecting pieces are numbered from the bottom left towards the top and again from the bottom right towards the top.

The simulation does not allow unconnected open flanges. The incoming fluids have to be able to leave the tank by means of other connecting pieces.

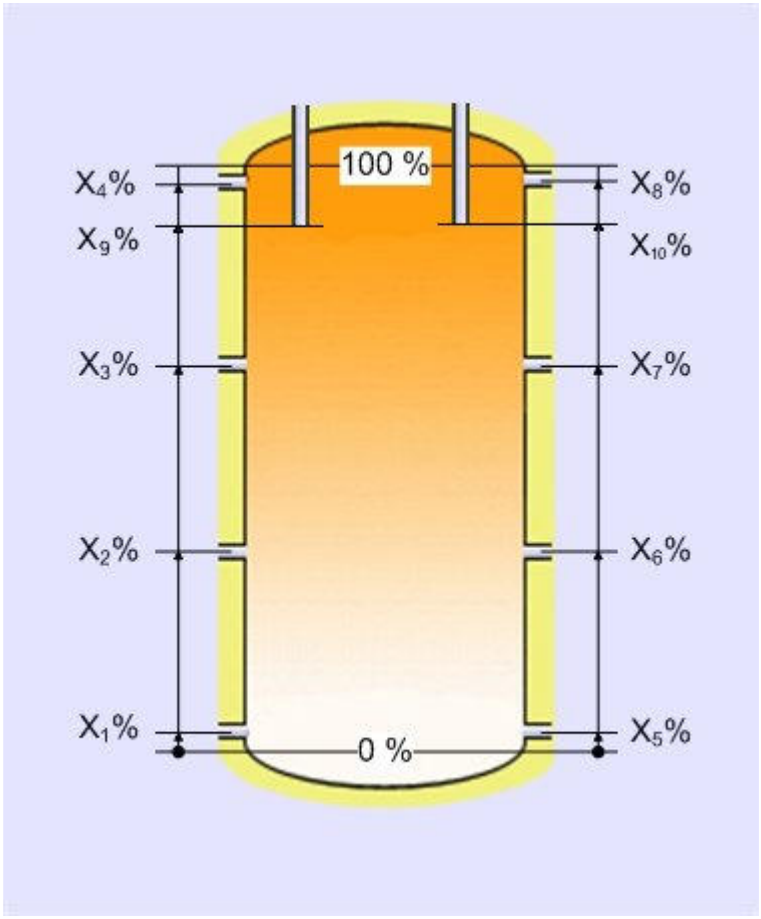


Figure 27: positions of connecting pieces

A tank has up to six coil heat exchangers available. Three coil heat exchangers can be connected to the left internal tank wall and three to the right wall of the tank. This variant is illustrated in figure 20. The height of the coil heat exchangers is indicated in millimeters in the catalogue “Coil heat exchangers”, its position in the tank is indicated in percentage from the top edge of the coil to the lower part of the cylinder.

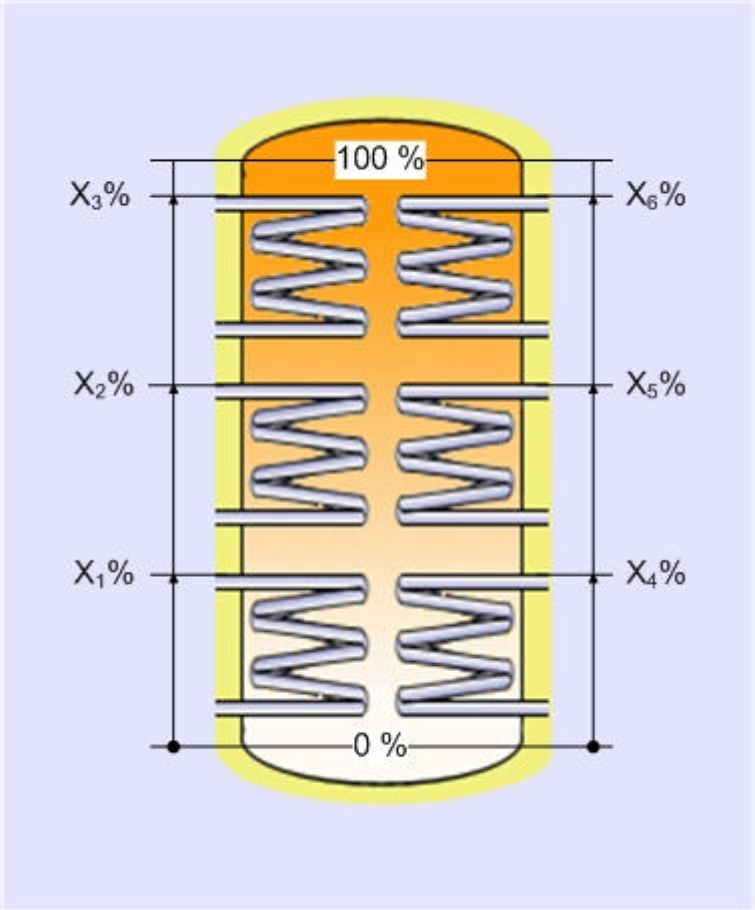


Figure 28: arrangement of coil heat exchangers

The three internal elements “tank”, “tube” and “coil heat exchanger” are defined as shown in figure 21. Furthermore they have available positions from one to three, that can be substituted by choice with the three objects.

The volume of an internal tank is defined in function of the relative surface and the relative positioning. The height of the internal tank is calculated on the basis of the indications of its position.

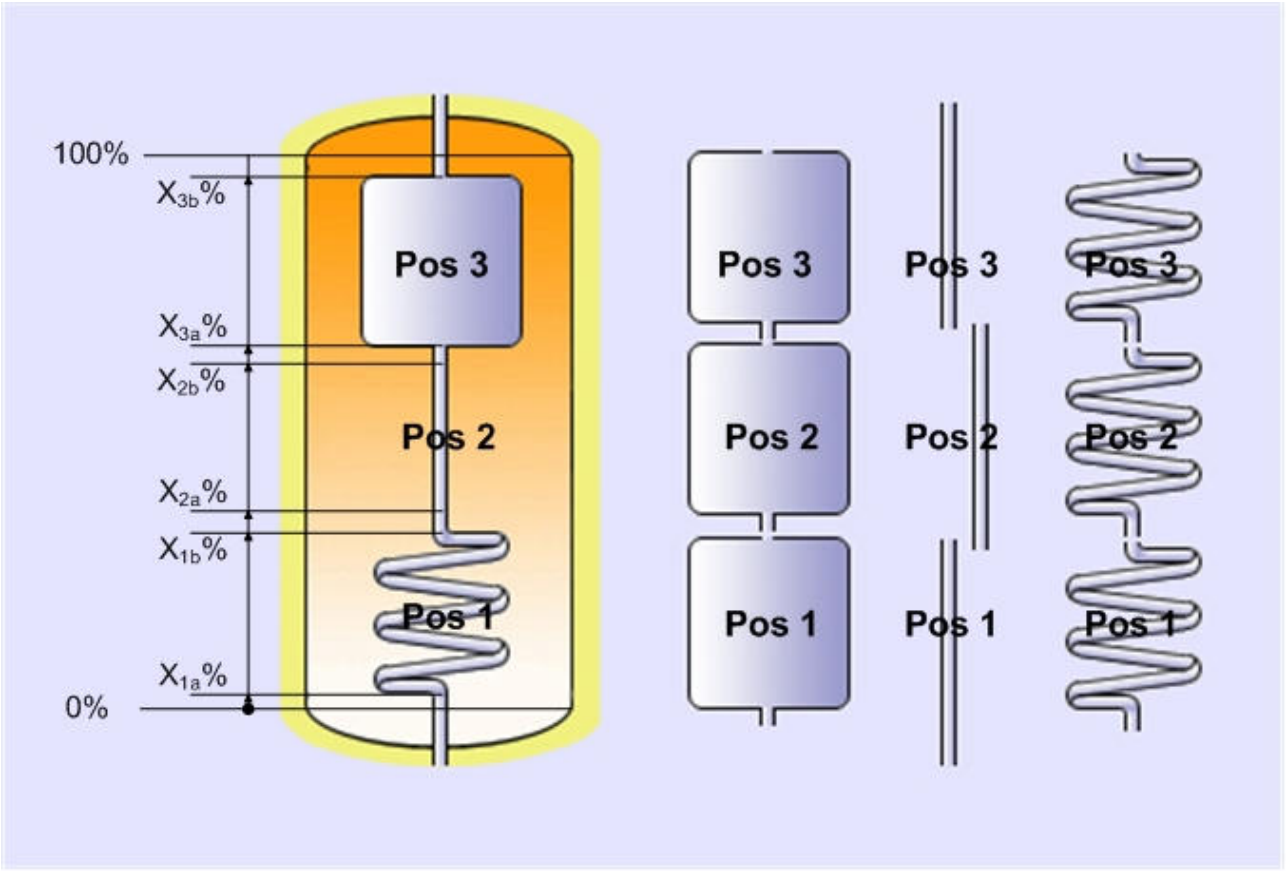


Figure 29: positioning of internal elements

It is possible to have up to four stratifier lances, arranged and numbered from left to right. In the tank catalogue only the position is defined, the measurement is indicated in the “stratifier lances” catalogue.

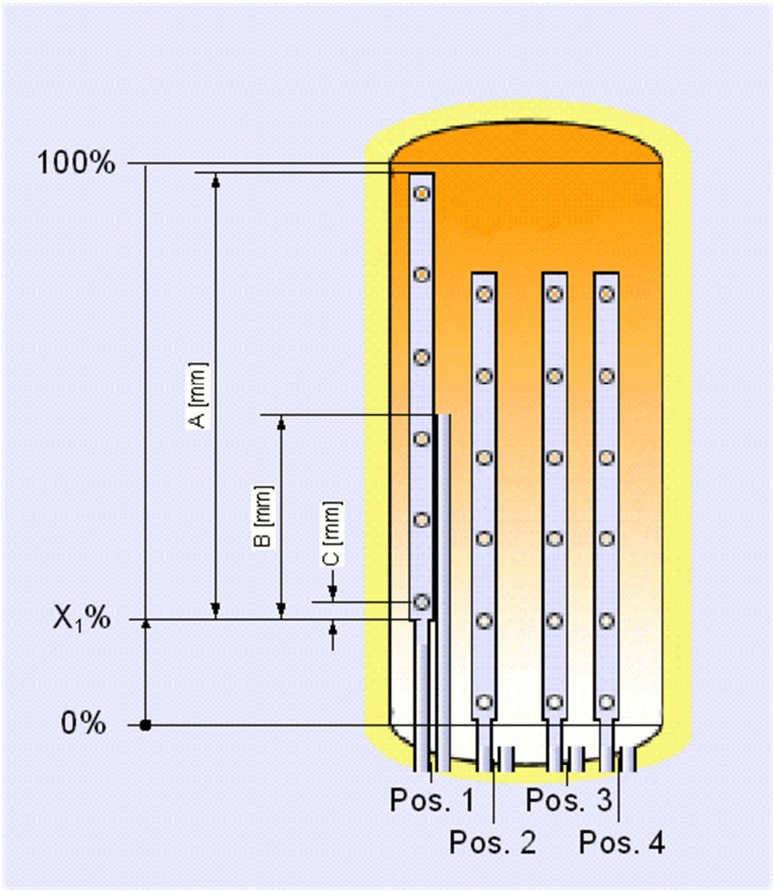


Figure 30: measures and arrangement of stratifier lances (A= length, B=return, C=lower inlet)

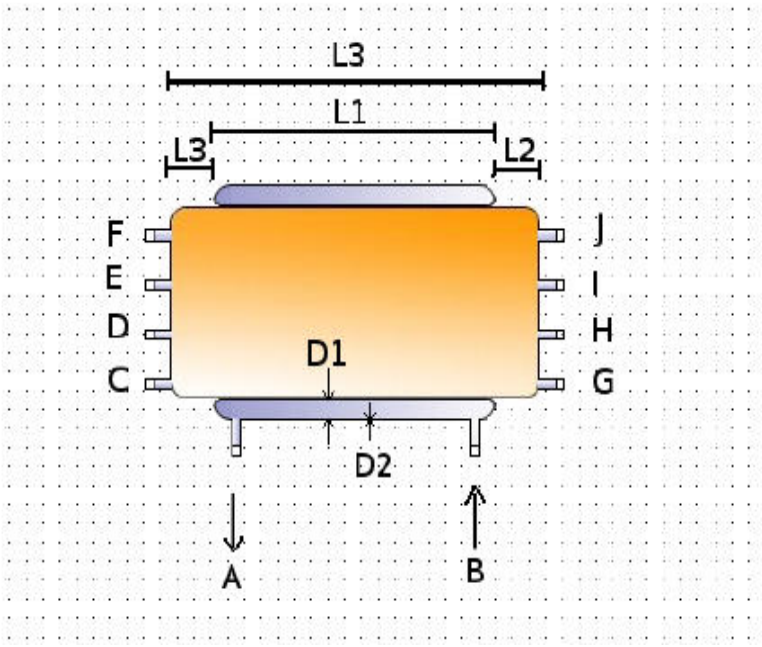


Figure 31: measures and arrangement of horizontal tank with coat heat exchanger (A = fluid outlet, B = fluid inlet, C = port 1, D = port 2, E = port 3, F = port 4, G = port 5, H = port 6, I = port 7, J = port 8, L1 = length of the heat exchanger → L4-(L4(100-L2)/100)+(L4*(100-L3)/100), L2 = position of the heat exchanger's bottom edge in % of the total height of the tank, L3 = position of the heat exchanger's top edge in % of the total height of the tank, L4 = tank height, D1 = thickness of the coat heat exchanger, D2 = thickness of the heat exchanger's walls)*

5.5.2.5 Thermal insulation and losses at connections

The design of seasonal tanks depends strictly on the possibility of thermal insulation and the way in which the heat lost from the tank can return to become useful for heating the space (for example when the tank is in the centre of the house). Relative to losses, a large tank is more convenient than a small one because the relationship between surface and volume (even in proportion) is lower when the tank is large.

Normally thermal insulation with a thickness of 15-30 cm is used (with a heat conductivity coefficient of $\lambda = 0.04$ *W/m/K*). The top cover can be thicker because hotter water is found there. The bottom cover, on the contrary, can be much thinner. In certain cases it is actually worth the trouble to omit the thermal insulation on the lower side. This way the environmental heat helps to warm the cold water.

In the course of planning, these various aspects need to be taken into consideration. Also the particular characteristics of heat input (from the collector and auxiliary heating) and from heat output (consumption of hot water and heating) are determining factors.

The illustration of the dialogue window for the definition of relevant parameters of the tank in Polysun follows:

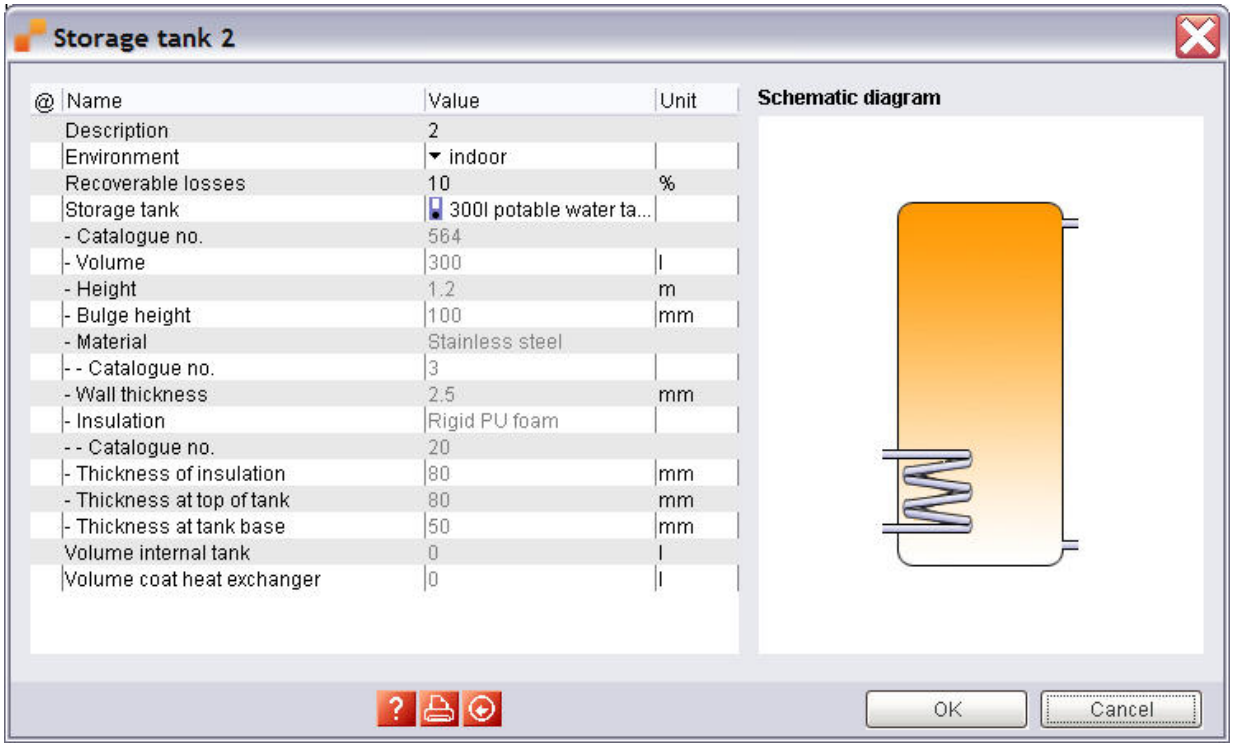


Figure 32: tank dialogue

To modify the properties of the tank (for example the volume), you can open the tank catalogue by double clicking on the catalogue symbol in tank. At this point it is possible to select another tank or to copy and adapt the one in use (at the Professional and the Designer level).

With “connection losses” we mean that the pipes from and to the tank can be the source of considerable losses. For example in the hot water connection pipe (in stasis) the hot water continually rises, it cools and descends again in the tank. This can cause considerable heat losses. Regarding this, two solutions exist:

S-bending the pipes and insulating the connections: right at the output of the tank a downward curving piece is installed. Here the water cools, but remains at this point in the pipe, impeding further exchange of hot water. If and how to curve and insulate well the connection can be chosen in the tank catalogue. For the simulation, losses at the connections are determined, that are defined in the flanges (connections) catalogue.

The extent of losses also depend on the temperature of the storage tank room. This can be indicated locally in the project. The indicated values are valid for S-bent and well insulated connections. Without these measures the losses at the connections are 10 times higher.

5.5.2.6 Charging the tank

To transfer the heat from the collector to the tank in the most efficient manner, different methods are employed:

- **Internal heat exchanger:** the fluid is pumped through a coil that is found inside the tank. The pipe in the form of a spiral should have a wall that is quite thin with a large (external) surface (for example thermal fins) and made of material with a good thermal conductivity (for example copper). The heat is transmitted by means of a (free unilateral) convection to

the fluid in the tank.

- **Coat heat exchanger:** The fluid flows around the tank through the coat heat exchanger encasing the tank. The heat is transferred to the fluid in the tank through (one-sided free) convection.
- **External heat exchanger**: the fluids of the collector and that of the tank are conducted one near the other in a counterflow plate heat exchanger and exchange heat by means of thin fins, which separate the two liquids. This is an efficient model of heat exchange in which, depending on the capacity of the exchanger and the ratio of temperature and flow, up to 99% of the thermal energy can be transmitted from one liquid to another. Normally on the tank side of the heat exchanger a circulation pump is also found. After the heat exchange, the fluid is released to the tank by means of one of the following variants:
- **Direct introduction**: the heat transfer fluid is withdrawn and introduced directly into the tank.
- **Introduction by means of a stratifier lance**: inside the tank there is a vertical tube with about a dozen apertures covered externally by movable caps, similar to a flute. The fluid rises inside the tube until its density is greater in respect to that present in the corresponding point in the tank, and then flows out. The fluid is therefore "deposited" exactly at the point in which it has the same temperature as the tank's liquid. This way an optimum stratification is guaranteed in the tank. Polysun doesn't yet contain stratifier lances with internal heat exchangers, whose simulation is carried out by means of an external plate heat exchanger, as indicated in figure 25. A fixed flow rate must be selected in the pump, in order to have a balanced flow capacity ($m_1 * cp_1 = m_2 * cp_2$).

There are also cases in which two exchangers are employed, one at top and one at bottom of the tank. Depending on the solar irradiation and the temperature inside the tank, the energy is used for pre-heating (only the lower exchanger) or for the production of domestic hot water (both exchangers).

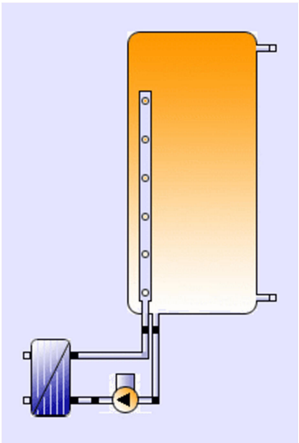


Figure 33: plate heat exchanger and stratifier lance

5.5.2.7 Withdrawal of water from the tank

There are two ways to withdraw heat from the tank:

- **Direct withdrawal** from the tank: the hot water is taken directly from the tank and is brought together with cold water to the desired temperature by means of a mixing valve (if the temperature of the highest layer in the tank is too high).
- **Internal heat exchanger**: the heat is withdrawn from the tank by means of a coil heat exchanger. The hot water is brought together with cold water to the desired temperature by means of a mixing valve.
- **External heat exchanger**: The heat is withdrawn from the tank by means of a plate heat exchanger. The control of the flow indexes must be regulated in such a way that the produced hot water has the desired temperature.

Deciding whether to choose a heat exchanger or direct drain depends on the conception of the circuits. There are systems in which the collector loop and the tank are operated with water, in some only the collector loop is operated with a mix of water-glycol and in others the collector loop and the tank are operated with a mix of water-glycol. To make this kind of choice it is useful to take the following into consideration:

5.5.3 Heat transfer media (mix of fluids)

- **Danger of freezing in winter:** if we consider that the external temperature can reach below zero, an anti-freeze product would be used (normally glycol). The higher the quantity of glycol, the lower the thermal capacity of the fluid. Ethylene glycol is normally used at a concentration of 33% (propylene glycol at 38%). In this way the fluid only freezes “like gelatin” without causing explosive effects inside the collector.
- **Calcification of the system**: for this condition there are two aspects to consider: if pipes with a small internal diameter are used inside the collector, calcification may obstruct the collector over time. Calcification may become a problem also in the tank. The situation is further aggravated if water is brought to temperatures above 60°C.
- **Sterility of the tank**: if domestic hot water is ready for use in the tank, there is a possible risk of legionella bacteria. This can be avoided by periodically heating the tank to above 65°C. In domestic hot water systems with an annual degree of coverage above 50%, sterility in summer is guaranteed by the temperature of the season.

For the choice of the system, cost considerations naturally also come into play. External heat exchangers are normally more expensive than internal ones, they require an auxiliary pump, but have greater transfer efficiency than internal heat exchangers. External heat exchangers are used above all in large systems, where the higher expense is compensated by greater efficiency.

5.5.4 External heat exchangers (plate heat exchangers)

Polysun makes available some types of systems with internal heat exchangers and others with external heat exchangers. The transfer rate of the exchanger is higher when the surface area of transfer is larger (that means the overall surface area of the heat exchanger), the thinner the walls of the tubes and the greater the conductivity of the material of which the heat exchanger tube is made of. Finally the fluid velocity in the tube is important, which depends on the flow rate. The number of “parallel heat exchanger coils” indicates how many exchangers are used in parallel (for example arranged one in another).

In an external heat exchanger a “fixed entry height” or a “variable entry height” (of a stratifier lance) may be chosen. It is possible to define the lowest position or the highest position of the stratifier lance. Curiously the optimum height of the stratifier lance is not the highest layer, but at about ¾ of the tank height. It results that in the upper part of the tank there is no “perfect” stratification, but heat losses are not as high at the top cover. The stratifier lance should reach at

least the level for daily consumption requirements.

The product of the thermal transmission coefficient k [W/m^2/K] multiplied by the transfer surface A [m^2] gives the thermal transfer rate of the heat exchanger, which results in the order of thousands of W/K. The parameter Δt indicates that which is (or should be) the difference in hot water temperature between the collector and the tank, in order to transfer to the tank by means of the exchanger the power density of 500 W/m^2. This parameter depends on the transfer rate and the surface area of the collector.

The volumetric flow rate on the collector side can be determined by means of the flow rate. The volumetric flow rate on the tank side is determined by the fact that the capacity flow rate (= flow rate multiplied by the heat capacity of the fluid) is the same on both sides of the heat exchanger. If a glycol mix is being used in the collector loop, but only water in the tank, the two volumetric flow rates are not the same.

5.5.5 Heat exchanger in the consumption loop

The use of the heat exchanger in the consumption loop doesn't only regard the fact that heat needs to be transferred in the most efficient way possible, but also that the desired water temperature needs to be reached. For this reason pump regulation in respect to the tank of the heat exchanger is provided for, in such a way that the user can directly obtain water at the desired temperature.

The temperature that needs to be found in the upper part of the tank in order to obtain the desired water temperature is indicated in the lowest line of the dialogue under "minimum tank temperature required". It depends on the temperature of hot-cold water, transfer rate and nominal flow rate. The nominal flow rate indicates the maximum quantity of hot water received per unit of time. The corresponding "withdrawal power" is indicated, too.

5.5.6 Auxiliary heating

In most cases, solar energy systems are used as support to conventional systems for the heating of hot water. During the summer auxiliary heating is most often inactive, while during the winter it forms the main contribution to heating.

Electric auxiliary heating is often used to lighten the work load of the boiler in summer. Normally, by installing a solar energy system, the use of auxiliary electric heating is canceled. As electrical energy is more expensive compared to oil or gas, the use of night-time electrical power, which is the most economical, can be convenient (this can be defined in the detailed dialogue of the controller). In Polysun, auxiliary electrical heating is carried out as an internal element of the tank, while gas or oil auxiliary heating is in the form of a separate component.

The design of auxiliary heating, that is the height at which the inlet and the return are installed, where the temperature sensors are placed and at which temperature the heating is activated or turned off, plays an important part in the efficiency of a solar power system. If for example in the afternoon solar energy will be produced, there is no need to keep the boiler on until noon. In real systems, but also in the simulation of Polysun, it is possible to establish the precise times at which auxiliary heating (in case of need) comes into operation. The auxiliary heating is programmed on the basis of the orientation of the collectors. It makes sense to introduce auxiliary heating only if after the irradiation of the collector, the level of required heat has not been reached in the tank. According to the consumption profile it could also be useful, directly before a peak in use, to make available the quantity of necessary heat in conditions when the sun hasn't provided sufficient energy. This way the tank losses are reduced to the minimum and a good possibility to find favourable working conditions (low tank temperatures) is given to the sun.

In Polysun, as in real heating systems, it is possible to define the operating times. Controllers are

used for this purpose (see below).

The quantity of heated energy is defined as the product of the “heated volume” multiplied by the difference in temperature of hot and cold water (multiplied by the capacity of the fluid). The volume is given from the contents of the entire tank and the layer in which the electrical immersion heater and the temperature sensors are found.

In defining the project, on the page “Consumer”, the daily energy consumption (“Hot water: daily demand”) is indicated. If you want to be sure that the supply of hot water is guaranteed in unfavourable conditions, you have to make certain that, as in the example, the quantity of heated energy and daily use are approximately equal. In most cases you can choose lower quantities of heated energy (for example electrical immersion heater in layer 10). This way the sun is given greater possibility to supply the necessary energy during the day.

The control of auxiliary heating can be carried out by means of two temperature sensors, which can be freely placed above the electrical immersion heater. It is possible to choose the on/off temperature in different ways, but the switch-on temperature must be lower than the switch-off temperature. The desired hot water temperature adopted in the example is 50°C. The switch-off temperature should always be a few degrees above this so that even after a few hours the tank temperature doesn’t drop too much. Finally, electrical energy is used only if an external temperature of at least 17°C is registered (i.e. in summer). This way great losses from the boiler are avoided for brief periods of operation.

Another frequent disposition is the use of a boiler for a temperature increase in the return (return shunt). In the case where a non modulating boiler is utilized, one must make sure that the boiler volume is large enough so that the fluid in the boiler doesn’t overheat (Polysun would at this point choose a very short time step, which would influence negatively on the simulation times).

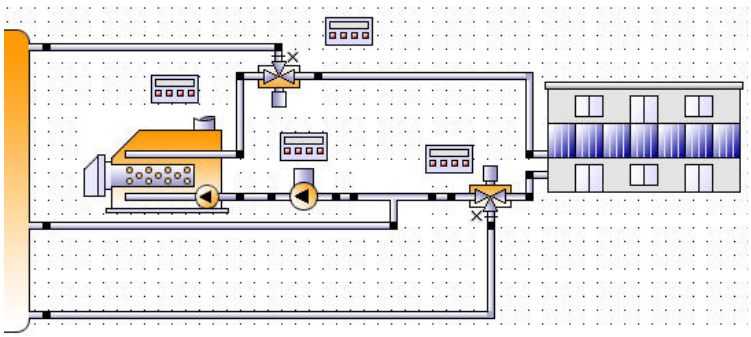


Figure 34: return shunt

Extended boiler model

In the boiler dialog box the user will be able to select an extended boiler model (New boiler). In this model the following physical quantities are also considered:

- Condensate recovery
- Difference bewteen heat loss to waste gas and heat loss to surroundings
- Cooling-off of thermal masses during downtimes
- Number of boiler starts and stops (boiler cycles)
- Amount of water generated by fuel combustion (calculated from the percentage of hydrogen stored in the fuel)

As a rule flue gas temperatures are documented in the test report and are to be made available to

Polysun. Flue gas temperatures lower than the boiler return temperature by more than 2 K indicate the presence of a downstream heat exchanger for air combustion pre-heating purposes.
For condensation heat recovery purposes besides their temperature also the relative humidity of flue gases must be known so that condensate recoveries may be calculated. To this end we assume that a maximum humidty value may not be exceeded in flue gases. This value is dependent on the given boiler.
Heat loss to surroundings consists of the sum of heat exchanger losses and combustion chamber losses.
The amount of energy transferred to boiler water is equivalent to the sum of fuel and flue gas energy minus combustion chamber losses. Losses are shown with a negative sign.

Fuel and CO2 savings

The use of the solar energy system enables to reduce both fuel demand and CO2 emissions. Polysun calculates savings based on a calorific value table and the annual average efficiency of the heat generator. Double-clicking on the heat generator and subsequently on the "Fuel" folder you will enter the Fuel catalogue. The catalogue provides the user with a wide selection of fuels. The professional version or higher will allow the user to create user-defined entries as required.

For fuel saving calculation purposes the Ssol solar energy in the tank is divided by the heating value of the fuel and the total yearly boiler efficiency.

$$Fuelsaving\,[unit] = \frac{S_{sol}\,[kJ]}{Heatingvalue_{fuel}\,[kJ/unit] \times total\ yearly\ boiler\ efficiency}$$

In electrically operated heat generators fuel savings would just match the Ssol solar heat provided to the tank. As Ssol is already available in the "Variant results" overview an oil equivalent was calculated for fuel saving purposes. The provision per kJ of electrical power requires about 4 kJ of primary energy in oil. This applies to currents from UCTE (Union for the Co-ordination of Transmission of Electricity) low-voltage networks and up.

With reference to CO2 savings the solar yield to the tank Ssol will be multiplied by the CO2 emissions from the fuel and divided by the yearly boiler efficiency.

$$Impeded\ CO2 = \frac{S_{sol}\,[GJ] \times CO_2 emission}{total\ yearly\ boiler\ efficiency}$$

Fuel and CO2 savings may be found under "Boiler" on the "Components results" page.

The data included in the Fuel catalogue (CO2 emissions and calorific values) come from the ecoinvent centre (Schweizer Zentrum für Ökoinventare).

5.5.7 Pumps

The pump model used by Polysun is based on the pump curve that regulates the flow rate foreseen in the circuit. In one circuit only a single pump can be employed. When not in operation, the pump blocks the flow.

The pumps can be subdivided into various types, according to which mechanism defines the flow rate.

- The flow rate is established by means of *circuit pressure drop*. The flow rate is calculated in correspondence to the pump curve that regulates the flow rate in the circuit.
- *Fixed flow rate*: the flow in the circuit is regulated by a pre-established flow rate.
- *Controlled flow rate*: a controller manages the pump flow rate.

Solar energy systems in which the collector is installed on the roof and the tank is installed in the basement require a circulation pump. Otherwise, due to the force of gravity, the heated fluid would remain above in the collector and the cold fluid below in the tank. The systems in which the collector is mounted below the tank can do without a pump. Such natural circulation (thermosiphon) systems require only a non return valve. In addition to saving on a pump, that is also tied to costs for electrical energy, such systems also present an inherent physical regulation, that in the presence of more intense solar irradiation allows the fluid to circulate more rapidly.

Often the collector is found above the tank, therefore forced circulation of the fluid is indispensable. The operation of the pump can therefore require considerable energy consumption. If a solar energy system works for 2000-3000 hours per year (in one year there are 8760 hours) the absorption of energy by the pump can in itself represent a certain percentage of the solar energy obtained. In well-planned large systems the consumption of energy by the pump is nevertheless lower than one percent of the obtained solar energy.

The specific flow rate is a measurement adapted to the definition of flow rate as directly linked to the maximum increase in temperature (heating of fluid by means of the collector). For example heating the fluid from 20 to 60°C is possible in the presence of full irradiation, high external temperatures and a low flow rate. At higher flow rates there is a corresponding lower temperature increase. The two techniques are respectively referred to as “Low-Flow” (10-20 $1/m^2/h$) and “High-Flow” (30-40 $1/m^2/h$).

The efficiency of the pump depends on among other things, the loss of pressure in the collector loop and on the collector area, but with these, pump efficiency increases linearly much less. A part of the heat lost by the pump (25-90%) is passed to the fluid and goes in favour of the thermal balance of the solar energy system. Still, this gain of energy is valued with scepticism because the consumed electrical energy is expensive and produced in an ecologically sustainable manner.

5.5.8 Piping

The pipes are the links between the various components of the solar energy system. Their role is primarily to transport the heat transfer fluid among these components with a minimum of heat loss. Thin pipes have the advantage of having low volume, requiring little fluid and the heated fluid is rapidly transferred from the collector to the tank. On the other hand they also cause great pressure loss, compared to pipes with a greater diameter, which causes an elevated power absorption by the circulation pump. In Polysun it is possible to separately define inlet and return pipes. It is therefore possible, to better insulate the (hotter) inlet or size the return pipes thicker to reduce the pressure loss.

To define the thickness of the pipes the following aspects are to be considered:

- Pipes with a large diameter have a **large surface area** and therefore greater heat loss
- Pipes with a large internal diameter allow for a **higher flow rate**
- In thicker pipes the fluid flow is **laminar**, something which slows the transverse heat transfer

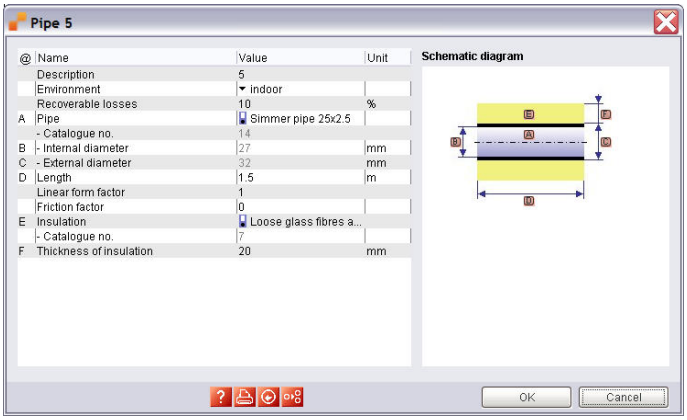


Figure 35: pipe dialogue

in the fluid and causes lower heat losses

- Thicker pipes (equal in length) have a greater volume, which presupposes a greater quantity of heat transfer fluid in the collector loop and makes the system inert.

In light of these considerations it can be deduced that the diameter of the pipe needs to be rather small and is substantially established by means of the criteria of suitable pressure loss.

The diameter and thickness of the pipe walls are given by means of a catalogue of commercially used pipes (copper and steel). In copper pipes the specification 22 x 1 indicates an external diameter of *22 mm* and a wall thickness of *1 mm*. In gas pipes the internal diameter is indicated in inches (*1 inch = 2.54 cm*).

5.5.8.1 Thermal insulation of pipes

The thermal insulation of piping is very important. During the transfer of heat to the tank one doesn't want to lose the level of collector efficiency attained with much effort. With the use of thermal insulation with some *centimeters* of thickness acceptable heat losses can be sustained.

The connecting pipes are to be insulated as much as possible starting from the collector outflow. The thickness of the insulation can be regulated by the following dialogue (double click on pipe):

The thickness of thermal insulation can be freely defined, as well as the relative thermal conductivity. Likewise determinant for the efficiency of the piping is the conductivity and the heat capacity of the used metal pipes. The total length of the piping can be indicated separately in the respective fields. In the simulation it is important to also consider details such as the length of indoor piping, in respect to the length of outdoor piping. In this regard two separate pipes are established (at the Designer level) where the insulation thickness and length can be inserted separately.

5.5.8.2 Pipe dimensions

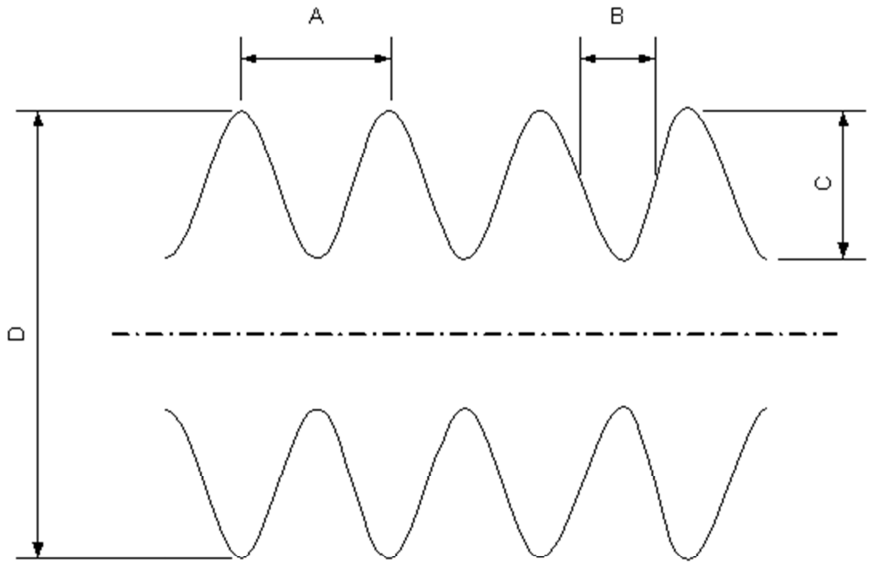


Figure 36: dimensions of a ribbed pipe (D = diameter, A = rib period, B = rib width, C = corrected depth)

5.5.9 Three-way valves

Three-way valves play a crucial role when it comes to the analysis of fluid loops. Three-way valves share the inflowing fluid-flow in a fixed proportion. The position of the mixing valve is adjusted by the controller. Based on the situation in the schematic system diagram the three-way valve alternatively distributes inflowing fluid-flows or brings together two separate fluid flows. The adjusted output is marked with x. If the signal of the controller is logically one the x output will be completely open. Both situations are schematically outlined in the following graph:

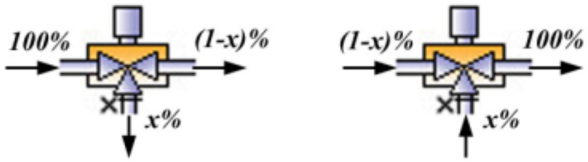


Figure 37: Three-way valves

5.6.9 Connection multiplier

This component allows hydraulic components and assemblies to be included several times in a simulation. The multiplier is, for example, interposed at the collector inlet to integrate all subsequent components time and time again by the selected multiplication factor. So that the system may work properly an appropriate counter-piece, i.e. an inflow multiplier is to be applied in the collector return. This procedure may be carried out in an analogous manner at any point of a heating loop.

5.5.10 Heat transfer fluids

The climatic conditions in central Europe make it necessary for solar energy systems to be resistant to temperatures below zero. This, for example, impedes the production of necessary hot water directly in the collector. When water freezes inside the collector, it destroys the collector by means

of its expansion. The water of the hydro network furthermore has the disadvantage that it tends to calcify the collector over time.

In order for the heat transfer fluid to be suitable for the above-mentioned needs, water is mixed with a certain quantity of glycol. In many cases ethylene glycol is used as an anti-freeze (for example Antifrogen L) or propylene glycol (e.g. Antifrogen N). From the moment the fluid circulates in a closed circuit, the danger of calcification is contained. For the mixing proportions the following various points of view are to be considered:

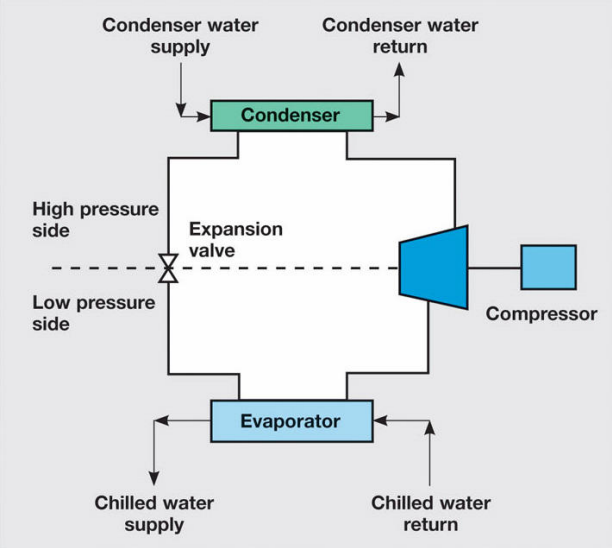
- The heat capacity of the fluid diminishes with an increased concentration of glycol
- Viscosity increases with higher percentages of glycol (problems with pressure loss)
- The freezing point drops with an increase in the percentage of glycol
- The boiling point increases with higher percentages of glycol
- Different possible chemical processes must be kept in mind, especially in passing through different metals
- The heat resistance of the fluid is to be considered

Freezing fluid is no longer a problem starting from a certain concentration as it no longer freezes as ice (crystalline), but rather in a grainy gelatinous form. Explosive effects are no longer evident. Beginning with a volumetric percentage of 33% (propylene glycol), or 38% (ethylene glycol), the fore-mentioned results take effect.

In Polysun the concentration of glycol can be defined. The corresponding physical properties for a temperature of 50°C are indicated.

5.6 Cooling systems

Two types of cooling machine models are available in Polysun: Compression and heat-driven chillers. Respectively, typical cycles of such chillers are shown in Figure38 and Figure39. As can be seen, the main difference of the two machines is the replacement of the compressor used in the compression cycle by three main parts in the heat-driven cooling cycle meaning absorber, pump, and generator resulting in much lower electrical consumption of the later cycle compared to the other. Another advantage of a thermally-driven chiller is that a waste heat such as solar thermal energy can be used to drive the machine at moderate to high temperatures with very good matching between the solar irradiation availability and the cooling demand during summer time. However, heat-driven chiller has lower coefficient of performance than that of compression chiller.



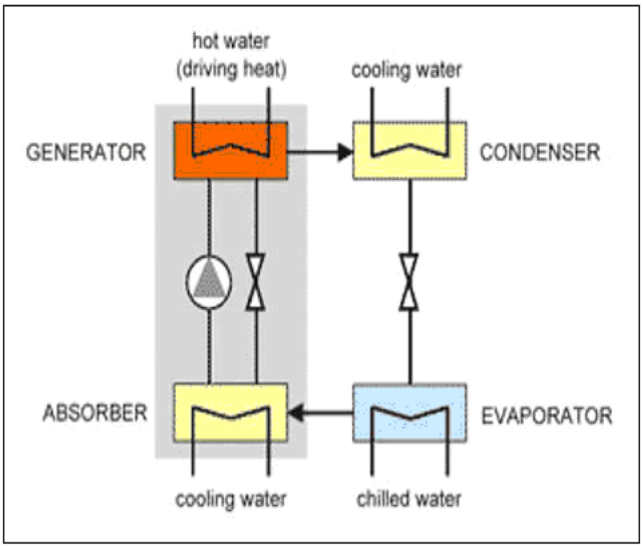


Figure 38: Compression cooling cycle

Figure 39: Heat-driven cooling cycle

5.6.1 Compression cooling model

The compression cooling can be provided through the current four port W/W heat pump component. Figure40 shows that three operation modes can be chosen from the drop-down list. Similar to the old heat pump model, cooling power output as well as electrical power consumption are calculated through linear interpolations of the measured points. Figure41 illustrates an available template in Polysun by which heating, hot water, and cooling demand can be provided through heat pump operating in “Heating and Cooling” mode. The ground-source loop is used as low temperature heat source in heating mode and in cooling mode it is used as heat sink. The necessary pressure failure set points have been implemented for cooling mode as well.

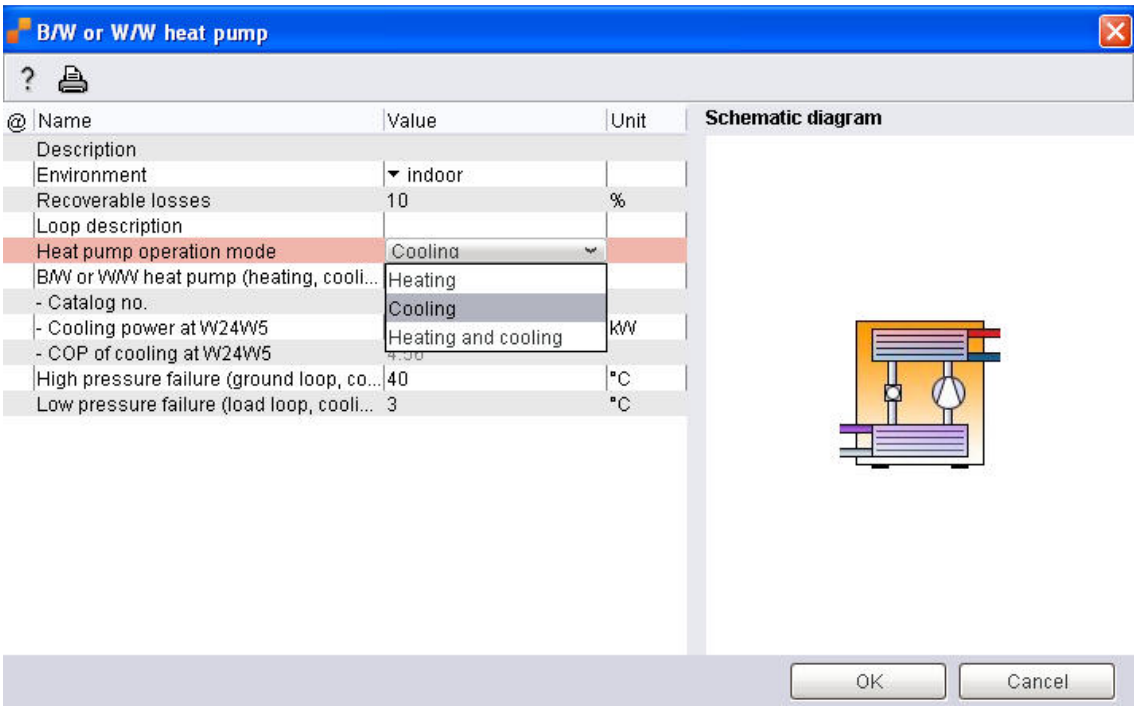


Figure 40: W/W heat pump dialog window. New heat pump model can operate in three modes: Heating, Cooling, and Heating and Cooling.

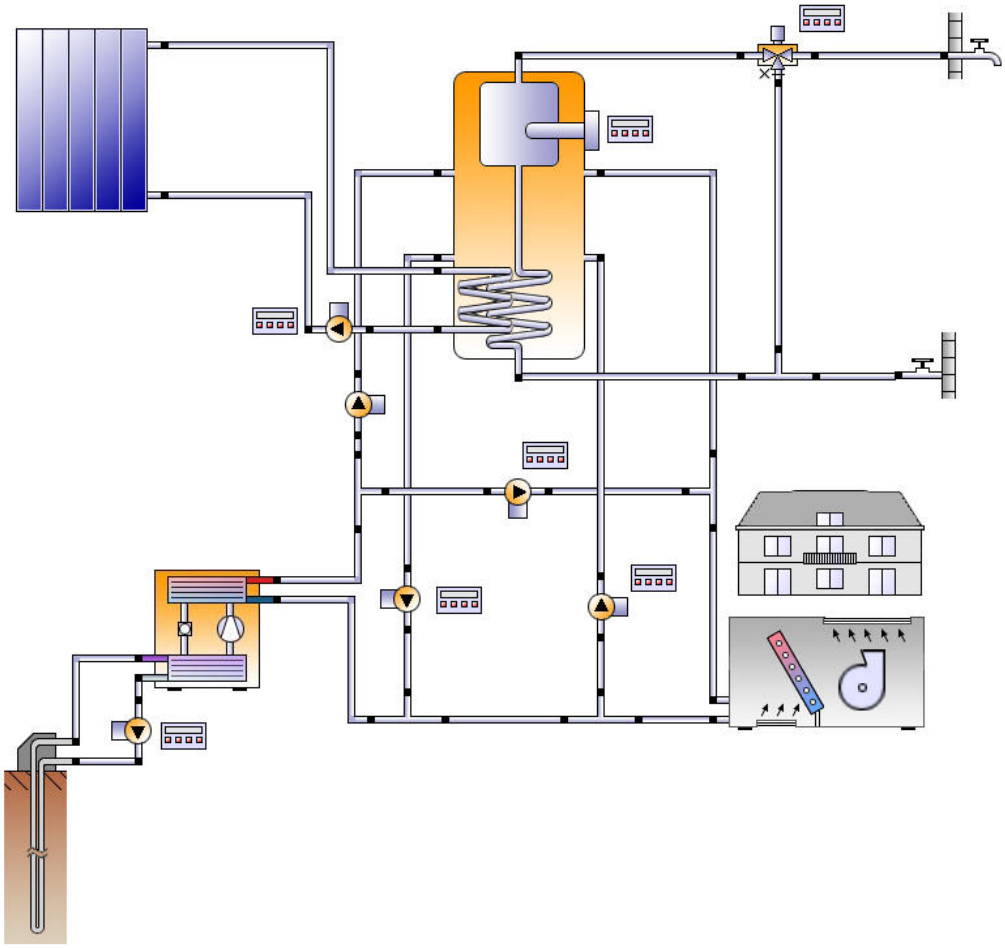


Figure 41: Heating, hot water, and cooling template using W/W heat pump as auxiliary energy source.

5.6.2 Heat-driven cooling model

The heat-driven chiller model in Polysun is based on absorption chiller cycle. Several theoretical or empirical methods have been proposed so far by researchers to model and simulate absorption chiller cycle. An analytic solution of the governing equations of the single-effect closed-cycle absorption chiller has been suggested by Kim et al. [1] which is used in Polysun. The main advantage of this model is that it can enable a quick simulation of absorption system with minimal information on working fluids and operation condition. The model is based on the heat exchanger effectiveness definition, Dühring equation and thermodynamic principles of the main constitutive components. The absorption machine model has three pairs of connecting ports enabling heat exchange between heat source, heat sink, and cooling load fluid domains over the component. The icons of absorption chiller and recooler (a heat sink to reject the heat from the absorption chiller's condenser to the ambient through cooling water circulation) are shown in Figure42.

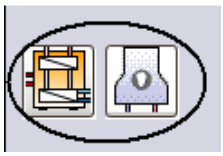


Figure 42: Heat-driven chiller (the left icon) and recooler (the right icon).

A number of different absorption cooling system configurations are possible to be simulated in Polysun. For an instance, A system is shown in Figure43 in which solar thermal collector field as well as the auxiliary gas boiler are used to provide heating demand during winter and to run the absorption chiller as heat sources during summer to compensate for cooling demand of the building. Domestic hot water demand is also provided through such a system all over the year. The type of recooler is wet in this layout which can be replaced by dry recooler, ground-loop, or pool. Two separated heat and hot water storage tanks are used in this system layout.

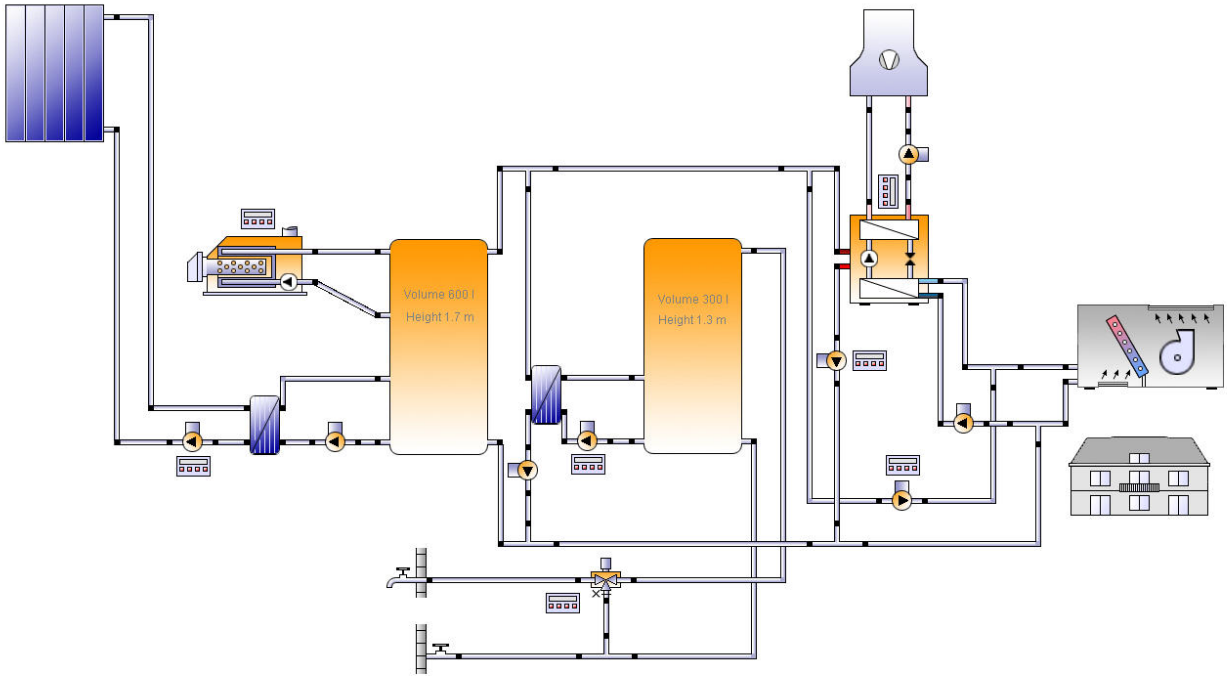


Figure 43: Solar-assisted absorption cooling system. The system also provides heating and hot water demands.

5.6.2.1 Six port absorption chiller concept

The notion of six port absorption chiller model is depicted in Figure44. The chiller is connected to three fluid domains namely hot water circuit (left side red ports), cooling water circuit (upper side pink ports), and chilled water circuit (right side blue ports). The main varying inputs into the chiller model are inlet hot, cooling, and chilled water temperatures and flow rates. The constant parameters used in the model are absorber, condenser, evaporator, generator, and solution heat exchanger effectiveness values and also solution mass flow rate circulated inside the machine. These values are called from absorption chiller catalog. Therefore, if necessary, these constant parameters should be changed carefully in the catalog based on information obtained from the chiller manufacturers. Such a component is flexible to be connected to different kinds of heat source such as solar thermal, heat sink such as wet/dry recoolers, pool, or ground-loop, and load such as fancoil, ceiling cooling etc.

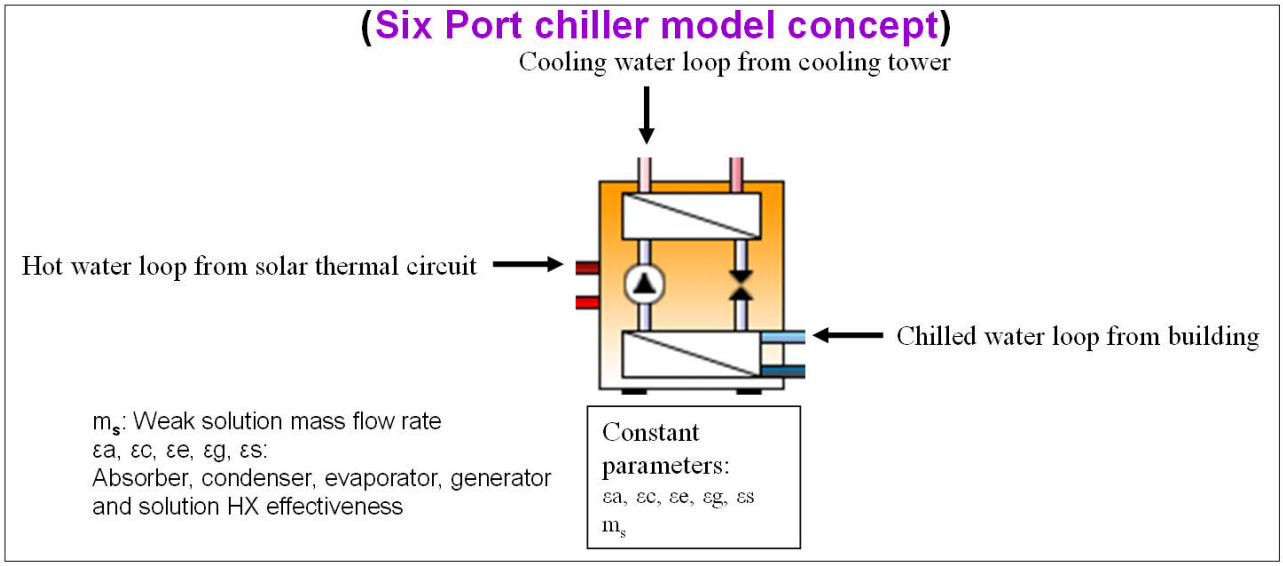

(Six Port chiller model concept)
Cooling water loop from cooling tower
Hot water loop from solar thermal circuit
Chilled water loop from building
m_s: Weak solution mass flow rate
εa, εc, εe, εg, εs:
Absorber, condenser, evaporator, generator and solution HX effectiveness
Constant parameters:
εa, εc, εe, εg, εs
m_s

Figure 44: Six port absorption chiller model concept.

The dialog window of the absorption chiller is shown in Figure45. As can be seen, different refrigerant/absorbent pairs i.e. Water/LiBr, Ammonia/Water, Water/LiCl, Water/ $CaCl_2$ can be defined in the catalogue. Design water temperatures and flow rates are also possible to determine. The four failure set point temperatures i.e. high and low heat sink temperature failure, high generator temperature failure, and low chilled water temperature failure have been implemented and can be set by user. These temperatures constrain the operation of the cooling machine to avoid abnormal condition e.g. crystallization phenomenon or very low performance of the chiller happens. As soon as one or more than one of these temperatures occurs during operation, machine will be switched off for a certain time span (Switch-off time) which can be defined by user. All mentioned controlling parameters are to be set according to the manufacturer technical advice.

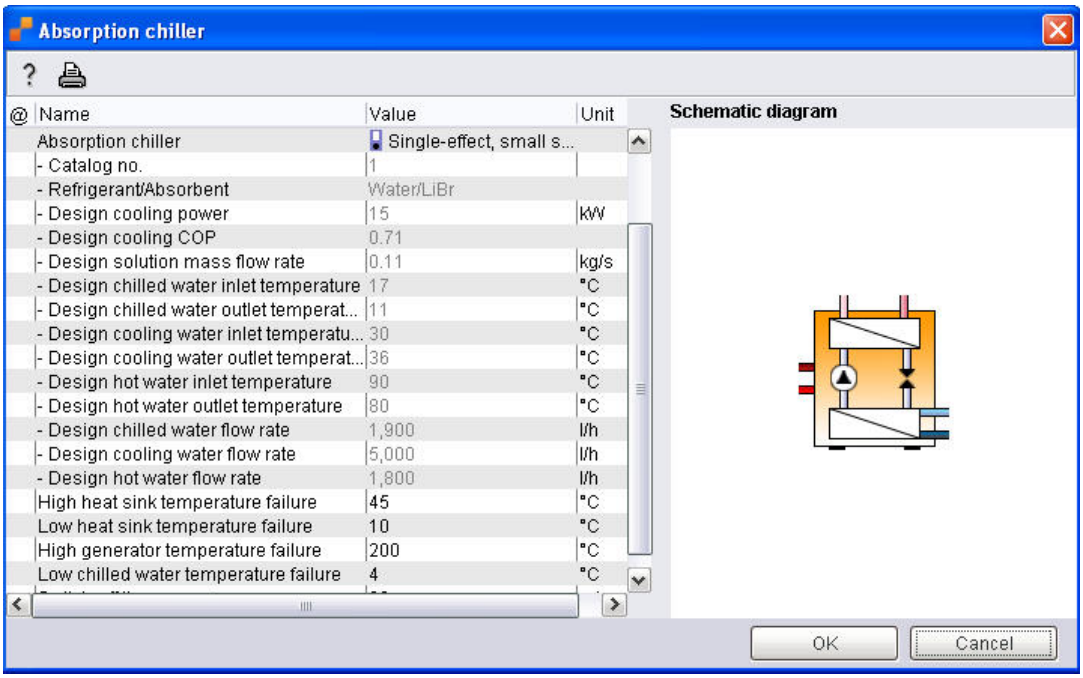


Figure 45: Absorption chiller dialog window.

The typical flow chart of the power exchange calculation over the absorption chiller model as well as controlling criteria on the operation condition is shown in Figure46. It is a magnificent fact that the proper controller(s) should be implemented on the chiller and the surrounding loops. The corresponding controlling strategies should be also set inside the controllers considering the cooling concept. It is always worth reading the available tool tips attributed to the properties inside the controllers.

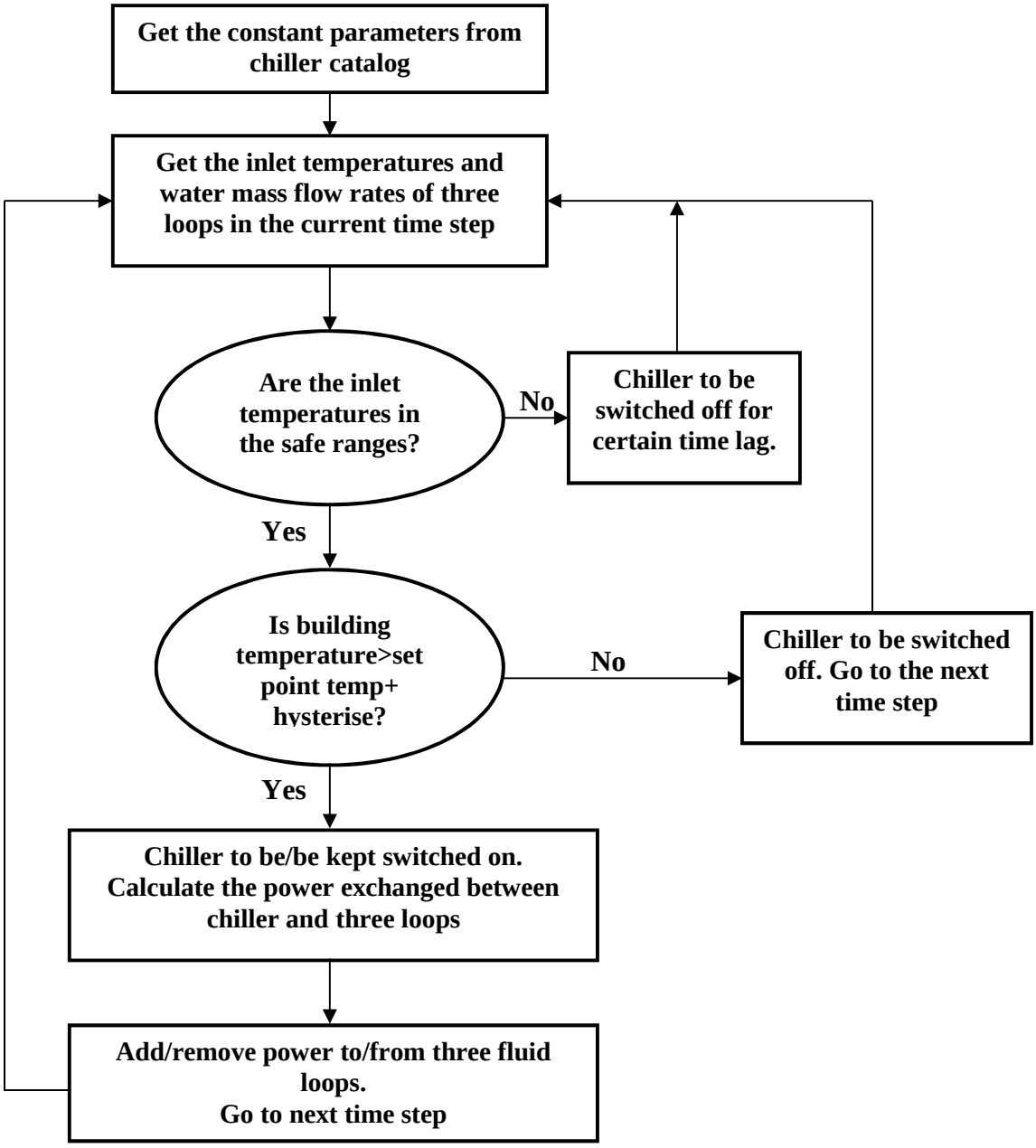

Get the constant parameters from chiller catalog
Get the inlet temperatures and water mass flow rates of three loops in the current time step
Are the inlet temperatures in the safe ranges?
No
Chiller to be switched off for certain time lag.
Yes
Is building temperature>set point temp+ hysterise?
No
Chiller to be switched off. Go to the next time step
Yes
Chiller to be/be kept switched on. Calculate the power exchanged between chiller and three loops
Add/remove power to/from three fluid loops. Go to next time step

Figure 46: The flow chart of absorption chiller operational procedure in Polysun.

5.6.3 Recooler model

As described above, different types of recoolers can be connected to the chiller component as heat

sink. Figure47 shows the dialog window of the “Wet recooler” or so called “Cooling tower” model. Cooling towers use the principle of evaporative or “wet-bulb“cooling in order to reject the heat from water. The main advantages over a conventional heat exchanger are:

- They can achieve water temperatures below the temperature of the air used to cool it.
- They are smaller and cheaper for the same cooling load.

The main disadvantage of cooling towers is their need for careful maintenance to minimize the risk of water fouling and water-borne organisms e.g. Legionnaire's disease.

There are two main types of cooling tower: ***forced draught*** and ***natural draught***. However, their principles of operation are identical. The present model concerns the forced draught type.

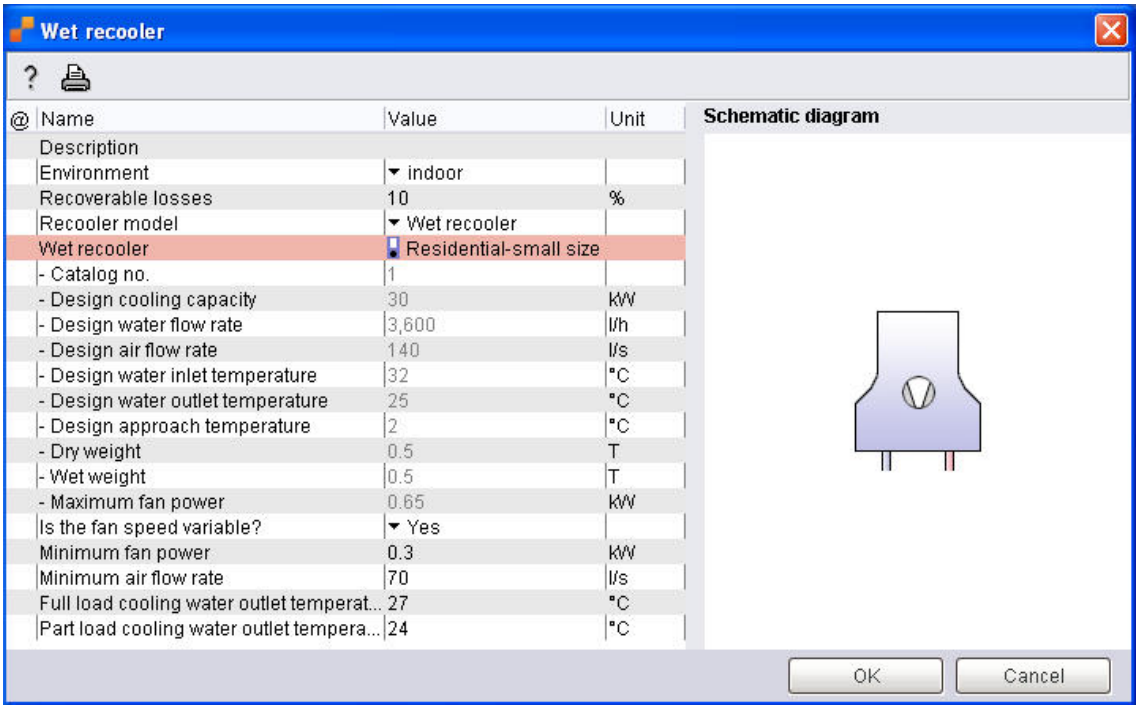

Wet recooler
@ Name Value Unit
Description
Environment indoor
Recoverable losses 10 %
Recooler model Wet recooler
Wet recooler Residential-small size
- Catalog no. 1
- Design cooling capacity 30 kW
- Design water flow rate 3,600 l/h
- Design air flow rate 140 l/s
- Design water inlet temperature 32 °C
- Design water outlet temperature 25 °C
- Design approach temperature 2 °C
- Dry weight 0.5 T
- Wet weight 0.5 T
- Maximum fan power 0.65 kW
Is the fan speed variable? Yes
Minimum fan power 0.3 kW
Minimum air flow rate 70 l/s
Full load cooling water outlet temperat... 27 °C
Part load cooling water outlet tempera... 24 °C
Schematic diagram
OK
Cancel

Figure 47: The dialog window of the wet recooler.

The model is based on steady-state condition using energy balance, mass balance, and mass diffusion relations on the incremental volume. The associated differential equations are simplified by using effectiveness approach model and the **Merkel’s assumptions** that is neglecting the effect of the water loss due to evaporation as [2]. The following assumptions are also made:

- Heat and mass transfer in the direction normal to flows only.
- Negligible heat and mass transfer through tower walls to the environment.
- Negligible heat transfer from the tower fans to the air or water streams.
- Uniform temperature throughout the water stream at any cross section.
- Uniform cross-sectional area of the tower.

To obtain accurate results, it is important to choose/implement an appropriate cooling tower according to the absorption chiller component size. As a rule of thumb, the cooling capacity of a cooling tower is almost twice as cooling capacity of the absorption chiller connected to it. Usually, cooling towers are rated based on their design cooling capacity, design water flow rate, design air flow rate, design water inlet/outlet temperatures, and also design approach temperature. The main

two performance figures of a cooling tower are **approach temperature** and **thermal efficiency**:

Approach temperature: cooling water outlet temperature- inflow air wet-bulb temperature

Thermal efficiency: $\frac{\text{cooling water inlet temperature - cooling water outlet temperature}}{\text{cooling water inlet temperature - inflow air wet bulb temperature}} * 100\ (\%)$

It can be observed that the thermal efficiency will increase as cooling water outlet temperature approaches the inflow air wet-bulb temperature. In another word, the smaller approach temperature also implies better thermal efficiency. Typical acceptable approach temperature is above 2.
As can be seen in figure47, the variable fan speed is also possible to apply. This feature would bring the advantage of reducing the fan power consumption during the part load condition. The operation concept of the variable fan speed is depicted in Figure48.

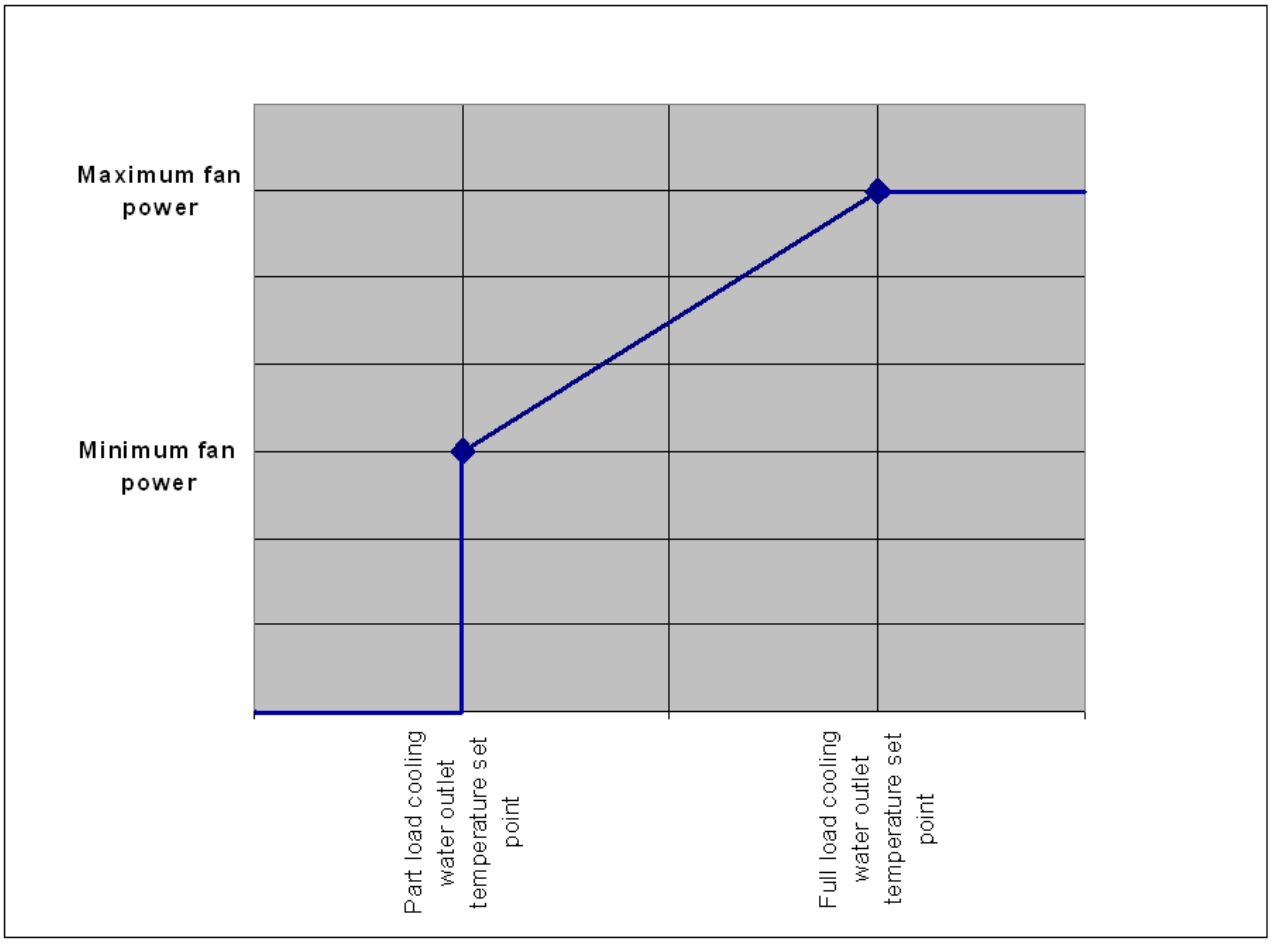

Maximum fan power
Minimum fan power
Part load cooling water outlet temperature set point
Full load cooling water outlet temperature set point

Figure 48: The operation control curve of variable speed fan.

5.6.4 Validation

The validation is always an important step in the modelling. A set of measured cooling powers of an existing absorption chiller machine were obtained. Comparison between such data and the corresponding results calculated by the implemented model is shown in Figure49. The design figures of the real machine are listed in the following table:

Absorption chiller type	Single-effect, Refrigerant/Absorbent: Water/LiBr
Design cooling power (kW)	35.14
Design COP	0.65
Design chilled water inlet/outlet temperatures (°C)	12.5/7
Design chilled water flow rate (l/hr)	5496.4
Design cooling water inlet temperature (°C)	31
Design cooling water flow rate (l/hr)	18351.7
Design hot water inlet temperature (°C)	88
Design hot water flow rate (l/hr)	8630.7

Figure49 reveals a good agreement between measured and calculated powers, especially in the neighbourhood of design condition, at different hot water and cooling water inlet temperatures.

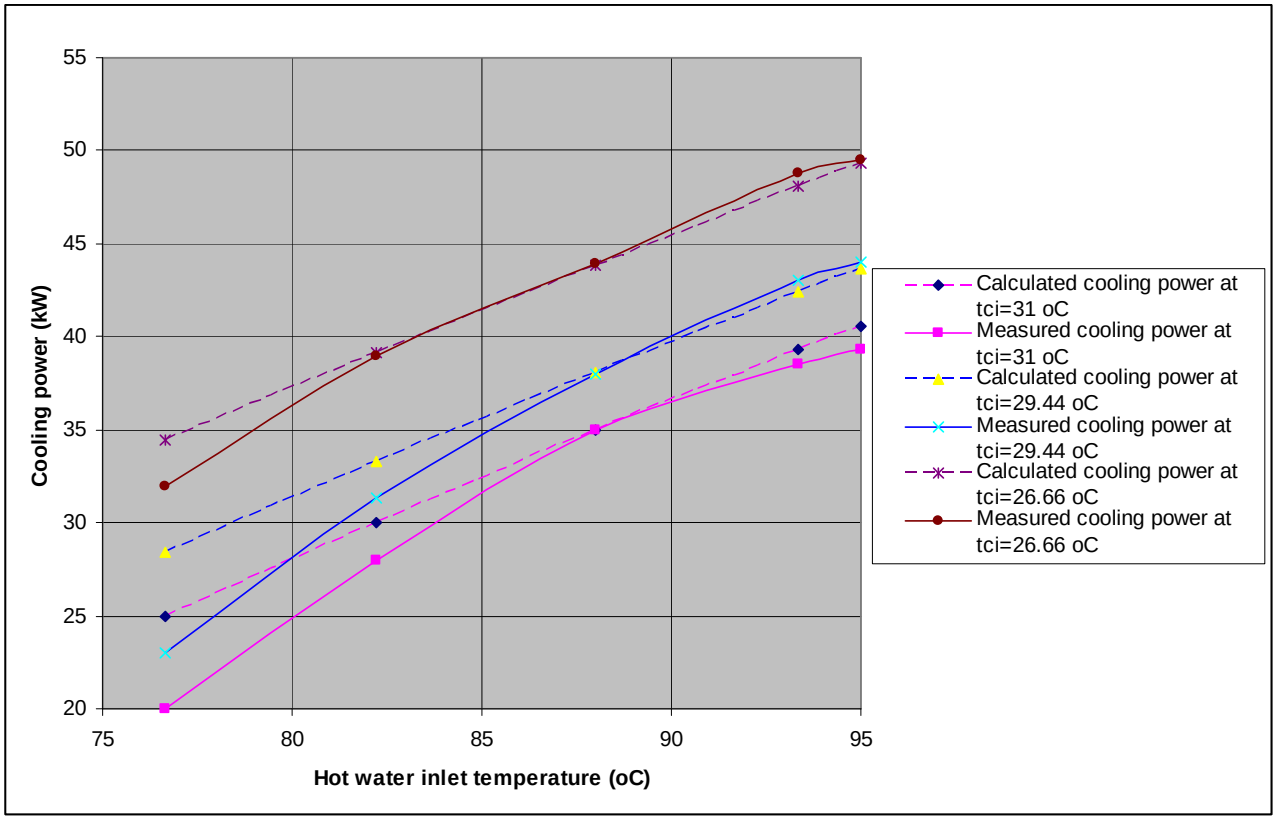


Figure 49: Characteristic curves of the absorption chiller. Comparison between measured data and calculated values. Cooling power versus hot water inlet temperature at different cooling water inlet temperatures (tci). Dashed lines: calculated values, solid lines: measured values.

5.7 Consumers

Demand profile and absence periods

The hot water consumption dialogue box allows users to choose between ”Profile“ and

consumption-specific “Monthly values”. As a standard six different VDI 6002 profiles are available for hot water. Each single profile can be individually adjusted to the required yearly demand.

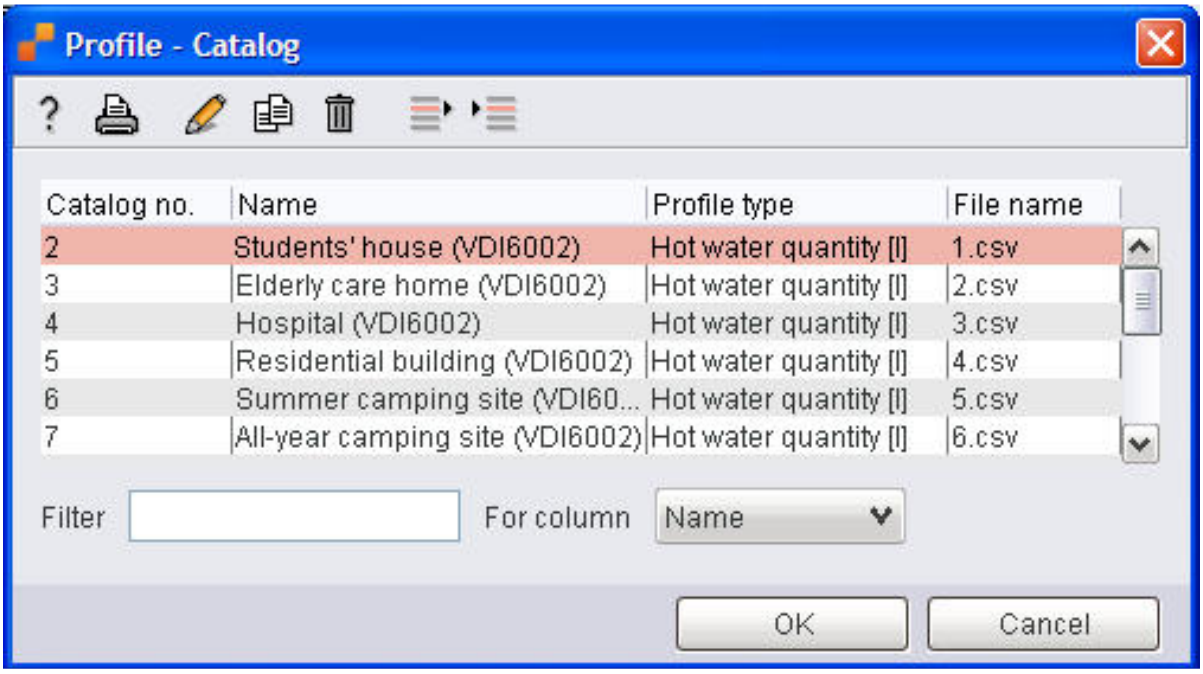


Figure 38: Profile dialogue box

The single files are stored in the “Profiles” folder in Polysun’s installation path. No existing profile file should be changed; Polysun runs a check before each use to ensure no file was manipulated. The software offers the opportunity to tailor profiles to one's individual needs. The file consists of two columns: the first column defines the time in seconds (from 0 to 31536000) when a change in hot water withdrawal takes place; the second column defines the corresponding hot water requirement (in litres) from this time on.

To best set-up a profile in Polysun the use of spread sheets like, for example, Excel is recommended.
Below is an extract of a profile:

…
18000;4.6
21600;4.6
25200;16
28800;16
…

This extract says that starting from second 18000 a water amount of 4.6 litres will be tapped; the same amount will then be tapped one hour later.

Remarks

- The software enables the user to create profiles with precision down to the second.
- All you need to do is copy a line in the profile catalogue, accordingly rename the file and select the correct profile type.

Energy requirements may be further differentiated by defining any absence periods (e.g. holidays)

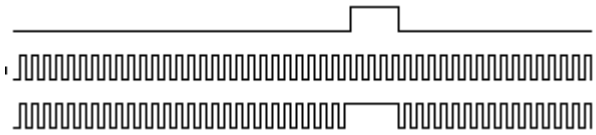
for hot water consumption (if a profile is not in use) and building model. During the defined period:

- No hot water is tapped.
- No ventilation is switched on in the building, the temperature is set to the night mode and no internal heat gain is added.

Absence periods (Period catalogue) may consist of multiple switching times. As soon as one of these periods sets in results also apply to the combination.

Ex.: the first period defines August as an absence period; the second defines all week-ends as an absence period. As a result all week-ends and August are regarded as absence periods.

August on:
Week-end on:
Result:



A start and end-date are defined for each period. The time running between the start and end-date is regarded as an absence period. Should the start-date be set to a later point than the end-date the absence period will extend over the end of the year.

Ex.: the start-date is set to November 1st ; the end-date is set to the end of February. As a result the period between the beginning of the simulation and the end of February and from November 1st to the end of the simulation is regarded as an absence period.

November to February:

A weekly repetition can be set for each day of the week. The repetition will be run between the start and end-date. The cut-in time corresponds to the start-time; the cut-off time corresponds to the end-time on the selected week-day.

Ex.: the start-time is set to February 1st 8:00 a.m., the end-time is set to March 31st 8:00 p.m. 20:00. The repetition is set on Wednesday. As a result in February and March each Wednesday the time between 8:00 a.m. and 8:00 p.m. is regarded as an absence period.

February 1st 8:00 a.m to March 31st 8:00 p.m., Wednesday:

5.7.1 Domestic hot water consumption

In a home, the consumption of hot water varies considerably according to the habits or the preferences of its inhabitants. For this reason the level of coverage by a solar energy system depends on the consumer's profile. In principle there is rarely a need for the water temperature to be higher than 50°C, except for the kitchen area, where sometimes the temperature requested is up to 55°C.

If the system is not set up optimally, according to the consumer's profile, unfortunate consequences may occur: if, for example, a lot of water is consumed in the evening, the tank temperature drops and, if too low levels are reached, auxiliary energy is introduced. In cases in which during the night auxiliary heating works too little, there is a lack of necessary hot water in

the morning.

The following parameters relative to domestic hot water can be inserted. The user can define

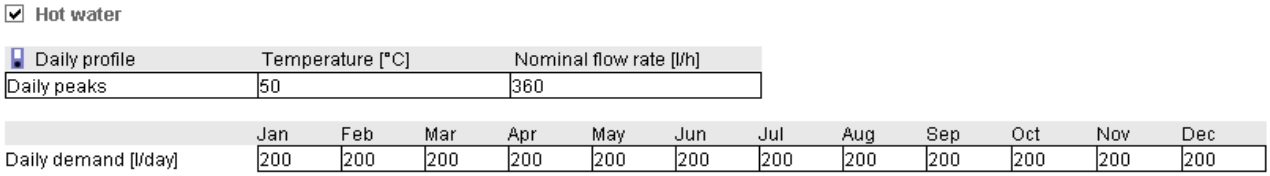

Hot water
Daily profile
Temperature [°C]
Nominal flow rate [l/h]
Daily peaks
50
360
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Daily demand [l/day]
200 200 200 200 200 200 200 200 200 200 200 200

Figure 39: domestic hot water dialoque

different consumption profiles for daily, weekly, and monthly values.

In many domestic environments the consumption of summertime hot water doesn't quite equal that of winter, depending on whether one wants to enjoy a nice hot bath in winter or a refreshing shower in summer. Such variations, that are verified over the course of the year, can be taken into consideration in the monthly consumption values.

The temperature of cold water in pipes varies according to region, on the average it is approximately 10°C.

5.7.2 Building simulation

Besides hot water for bathroom and kitchen use, solar thermal collectors can also be used to produce energy for space heating purposes. To this end heating water is pre-heated using the solar system. The remaining required energy is produced by means of an auxiliary boiler. Therefore a solar system with heating support may achieve a sufficient amount of solar energy an accordingly large surface will be needed. The storage tank too should have a larger volume.

All modern heating systems enable the desired type of control to be set manually. The system's energy consumption varies according to the selected setting.
For example with an outdoor temperature -10 °C the inlet temperature should be 45 °C. The temperature level of the transfer fluid running back through the system is 15 °C lower than at the tank outflow. The closer the outdoor temperature lies to the limit temperature; the lower is the difference between inlet and return temperature.
The energy reference area matches the living area (in m^2) to be heated, walls included. Non heated rooms such as garages and basements are not included. This allows the actual consumption to be scaled with greater precision.

For the specification of the controlled ventilation the air exchange rate indicates how often per hour the overall air amount is exchanged. The amount of heat that can be recovered by means of an air-air heat exchanger typically amounts to about 50% and can be likewise entered in Polysun (Parameter: *Efficiency heat recovery*). Additionally automated shading is taken into account (e.g. by means of shades or awnings): should the outdoor temperature rise above the entered *Shading temperature* the irradiance will be reduced by 90%.

The Polysun specific building template can likewise be extensively and individually adjusted. Should no specific heating loads be known the building will be defined based on editable basic dimensions as well as by means of a variety of building types included in the catalogue (with reference to a variety of international standard house types). The advantage presented by this template lies in the greater individualization opportunities given in the layout of the building structure as well as in the opportunity to accommodate multiple heating loops within the same building.

Further details arise from heating/cooling temperature setting data, conditions of use, building orientation, the presence of a heat recovery and/or cooling system, the presence of natural ventilation as well as the presence profile of occupants. Alternatively a building may be defined based either on a known heating energy demand or the annual fuel consumption (so called simple building model) by choosing “Energy demand known” as “Yes”.

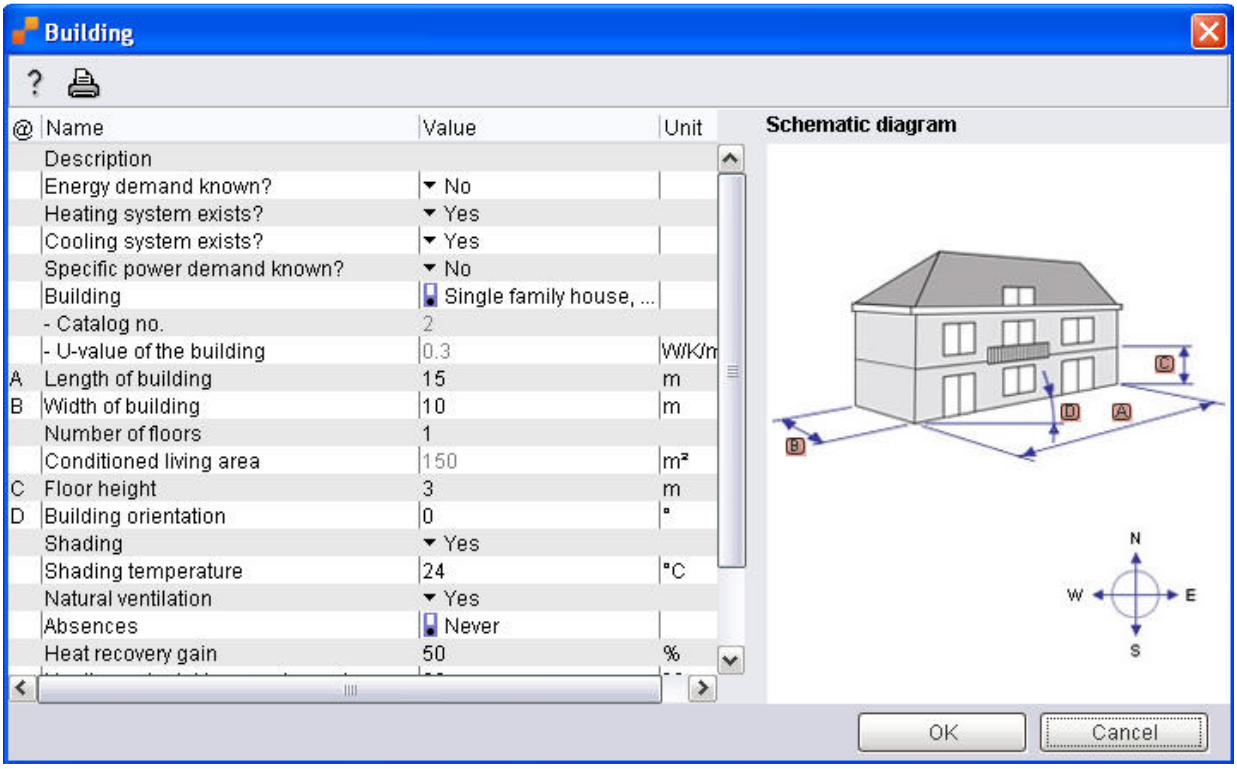


Figure 40: Building dialogue box

The building's dynamic thermal demand integrated in the simulation algorithm can be inferred from the compliance with the heating/cooling energy balance equation (displayed here in a simplified form).

$$HG - HL = MCp\frac{\Delta T}{\Delta t}$$

HG = HeatGain
HL = HeatLoss
MCp = thermal capacity
ΔT = Temperature variation per time step in the building
Δt = Time step

The equation takes into account both passive heat gains from the sun as well as the amount of heat generated by people living in the building, the air exchange rate, the type of lighting as well as any electrical appliances. A **W**indow-To-**W**all-**R**atio enables the influence of the employed glazing to be also taken into account. Depending on the type of window this reflects on the SHGC value (**S**olar **H**eat **G**ain **C**oefficient)
As a result the energy yield is composed as follows:

$$HG = G * SHGC * WWR + HGpeople + HGlight + HGequiptment + Gsys \quad [W]$$

G :Total solar irradiation on the wall [W]

$SHGC$:Solar Heat Gain Coefficient, value varying depending on the type of the window [-]

WWR :Window to Wall area ratio [-]

$HGpeople$:Heat gain dissipated by people living in the building [W]

$HGlight$:Heat gain dissipated through lightings [W]

$HGequiptment$:Heat gain dissipated by electrical equipments etc. [W]

$Gsys$:Heat gain/Heat removal through Heating/Cooling system (in cooling session it is a minus value) [W]

$$HL = HLtransmission + HLventilation + HL\inf iltration \text{ [W]}$$

$$HLtransmission = UA(Tin - Tout) \text{ [W]}$$

Where U is overall heat transfer coefficient of the building, A is total surface area of the building' envelope, Tin is the indoor temperature and $Tout$ is outdoor temperature.

$$HLventilation = (\dot{V}\rho Cp)freshair * (Tin - Tout) \text{ [W]}$$

Where $\dot{V}, \rho,$ and Cp are volumetric flow rate, density, and specific heat capacity of the fresh air delivered through ventilation system into the building interior respectively.

$$\dot{V}freshair = \frac{V * ACHventilation}{3600} \text{ [m}^3\text{/s]}$$

V :Building total ventilated volume [m^3]

ACHventilation: Number of air changes through ventilation system [1/hr]

$$HL\inf iltration = (\dot{V}\rho Cp)\inf iltration * (Tin - Tout)$$

$$\dot{V}\inf iltration = \frac{V * ACH\inf iltration}{3600}$$

ACHinfiltration:Number of air changes through infiltration

* In cooling session $HLtransmission$, $HLventilation$, and $HL\inf iltration$ are minus values.

5.7.3 Heat sink/source and heating modules

A simplified representation of a heating load may be achieved by means of the components "Heat sink" and/or "Heating modules" (radiators, floor heating, fan, etc.). The former are defined by means of fixed inlet, temperature gradients, flow rate and power range. The specified power levels can be freely edited from user levels Professional and above. The use of a heat sink is especially recommended for the representation of process-heat processes as power input ad output can be freely defined. The modelling of the heating module may be inferred from its specific emission characteristics as well as its power and flow ratio and inlet and return temperature. The values provided here enable a simulation to be carried out without the building-specific data defined in the consumer dialogue box. As a consequence, however, seasonal dynamics from the consumer side are no longer recorded.

5.7.4 Swimming pool

The swimming pool module is created as a component with two connections. The fresh water supply is taken into consideration, which can be inserted as a parameter. The physical models also include evaporation values, heat losses to the environment, convection, thermal emission and irradiation. The parameters used for the swimming pool are geometric measures (length, width, depth) also as the U-value between pool and soil.

The operating periods are indicated by the date (day of the month) and by the hour of opening (hour of the day). Also with “cover” and “gap losses cover” the user can indicate if and how the pool is covered at times of non-use.

Double-clicking on a swimming-pool out of the catalogue you will be able to select either an indoor swimming-pool or an open-air pool. For open-air pools room temperature, relative humidity of air and the recovery of heat evaporation are not taken into account. On the other hand wind portion and swimming-pool absorption have no influence on the indoor swimming-pool. The level of absorption of global radiation by the swimming-pool ranges based on colour, depth and covering between 60% and 90% (Duffie and Beckman 60%). The reflection of light on the water surface amounts to 8% and is already taken into account.

Definitions of fundamental parameters

A_{surf} = area of the pool surface in m^2
T_{pool} = water temperature inside the pool in $°C$
T_{amb} = ambient temperature in the air outside the pool in $°C$
v_{wind} = wind speed in m/s

Heat transfer to soil surrounding the pool

$$\dot{Q}_H = u \cdot A_{walls} \cdot \left(T_{pool} - T_{soil}\right)$$

A_{walls} = total wall and floor area in m^2

u = u - value in $W/\left(m^2 K\right)$

$T_{soil}(t) = \frac{\Delta t}{\tau} \cdot T_{soil}(t - \Delta t) + \left(1 - \frac{\Delta t}{\tau}\right) \cdot T_{amb}(t)$ with a temporal constant of □ = 7 days.

This corresponds to the formula $x(t) = 1 - e^{-t/\tau}$.

Heat losses due to evaporation from the water surface

Formula according to Transsolar (TRNSYS TYPE 114):

$$\dot{Q}_{Evap} = A_{surf} \cdot c_0 \cdot \left(c_1 + c_2\sqrt{v_{wind}}\right) \cdot \left(\hat{P}_{pool} - \rho \cdot \hat{P}_{amb}\right)$$

$$\hat{P}_{pool,amb} = k_0 + k_1 \cdot T_{pool,amb} + k_2 \cdot T^2_{pool,amb} + k_3 \cdot T^3_{pool,amb}$$

$$\rho = \text{relative humidity in } kg/kg$$

with the fit parameters [Auer96]

$c_0 = 1.01325 \times 10^5 \quad Pa/atm$

$c_1 = 42.39 \quad m/s$

$c_2 = 56.52 \quad \sqrt{m/s}$

$k_0 = 4.82 \times 10^{-6} \quad atm$

$k_1 = 7.11 \times 10^{-7} \quad atm/K$

$k_2 = -3.52 \times 10^{-9} \quad atm/K^2$

$k_3 = 7.22 \times 10^{-10} \quad atm/K^3$

The following illustration shows the influence of the wind and relative air humidity on the area related evaporation heat $\dot{Q}_{Evap}/A_{surf}$.

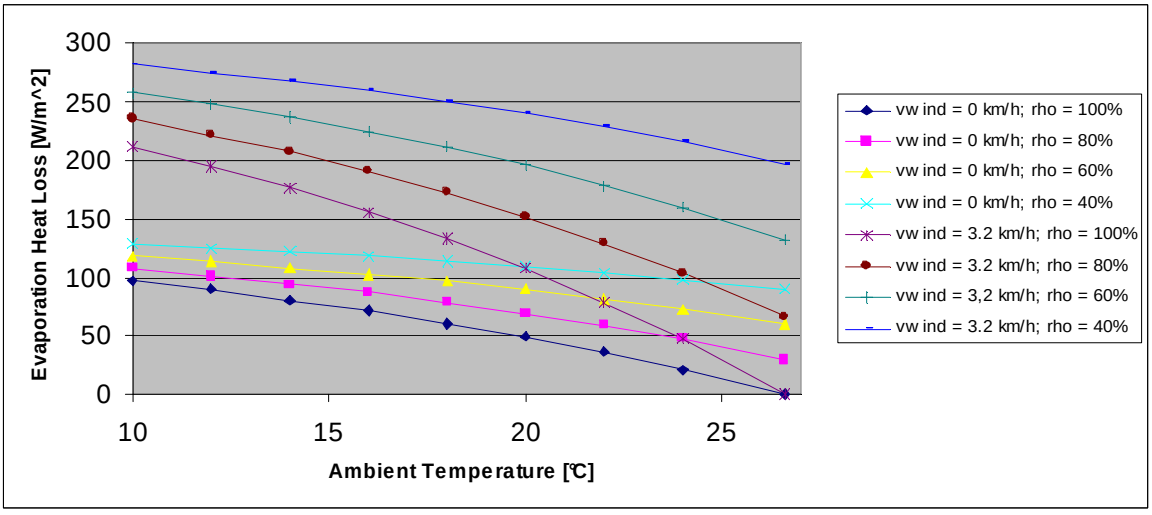


Figure 41: influence of wind and relative air humidity

Heat losses due to thermal emission

$$\dot{Q}_S = A_{surf} \cdot \varepsilon \cdot \sigma \cdot \left((273.15 + T_{Pool})^4 - (273.15 + T_{Sky})^4\right)$$

$\varepsilon = 0.9$

$\sigma =$ Stefan Boltzman constant $= 5.67 \times 10^{-8}$

Heat gains by means of direct solar irradiation

$$\dot{Q}_S = L_{up} - L + G_h \cdot (1 - \rho)$$

Heat losses due to convection

$$\dot{Q}_{conv} = A_{surf} \cdot (b_1 + b_2 \cdot v_{wind}) \cdot (T_{pool} - T_{amb}) \cdot \left(1 - \eta_{cover} + \eta_{cover} \cdot \frac{u_{cover}}{b_1}\right)$$

$b_1 = 3.1 W/(m^2 K)$ = heat transfer, no wind

$b_2 = 4.1 Ws/(mK)$ = correction term for finite wind speed

u_{cover} = u - value of the cover in $W/(m^2 K)$

η_{cover} = percentage of covered pool surface

Heat losses due to exchange of pool water (fresh water supply)

$$\dot{Q}_F = \dot{V} \cdot d \cdot c \cdot (T_{Pool} - T_{Fresh})$$

$\dot{V}$ = fresh water supply in l/h .

Normally: 2% of pool volume per day or 50 l a day per swimmer.

d = water density = $1 kg/l$

c = specific heat capacity of water = $1.16 Wh/(kgK)$

5.8 Ice storage tanks

Polysun allows for ice storage tanks to be simulated by means of an “Ice storage tank” component. In the “Ice storage tank“ component, the behaviour of ice storage tanks is depicted by means of a simple physical model.
Ice storage tanks operate by taking advantage of water changing its phase from liquid to solid (ice). The melting of ice at 0 °C to water at 0 °C requires about as much energy as heating up 0 °C water to 80 °C.

5.8.1 Model

The “Ice storage tank“ model is a simple model depicting a water-tank which, at temperatures near 0 °C, is able to absorb or release latent heat taking advantage of water changing its state from liquid to solid and vice-versa.
Ice storage tanks are arranged in a heat exchange relationship with the surrounding environment – the soil – as well as with the connected heat exchangers through which they are, in turn, connected with the other components. Their connection with the soil is depicted by a layer of soil connecting them with the temperature of the undisturbed soil.

5.8.2 Component

Other than by its temperature, the state of the water stored in the tank is also described by an ice-percentage ranging from 0% (fluid) to 100% (totally iced). The above ice-percentage is calculated from the latent heat.
The temperature of the undisturbed soil is calculated from the weather data for the relevant location.
Ice storage heat exchangers too include additional parameters to reflect the change in the state of water; for this reason, the “Ice storage tank” component can rely on its own heat exchanger catalogue. For the rest, the behaviour of heat exchangers is depicted analogously to regular tanks.
Ice storage tanks may be displayed both in the form of a cylinder and a cuboid.
For true-to-life simulation results, an adequately large start-up time should be set, e.g. 180 days.

6 Cogenerators

Polysun also provides for the simulation of *cogenerators*. Cogenerators work on the cogeneration principle to simultaneously generate both heat and electricity. Cogenerators are mainly used in decentralised energy supply systems for single or multi-family houses as well as for industrial plants.

6.1 Power modulation

A great number of cogenerators are non-modulating, on/off devices. As soon as a request is received from the controller, the cogenerator increases its output to a specific operating point, converting the fuel energy input into heat and electricity at a fixed ratio. In addition to these, cogenerator models also exist that can be operated within a given range by modulating their power output. Output modulation makes it possible to positively affect cycle behaviour and service life which, in turn, can have a positive impact on key factors such as maintenance intervals and economic viability.
In the catalogue, the power range of the respective cogenerator may be defined by means of two reference points, the maximum and minimum operating point based on the fuel power input. The fuel power input, the thermal efficiency value as well as the electrical efficiency value are required for each reference point. Should it not be possible for the cogenerator to be operated in modulating mode, matching minimum and maximum values should be entered.

Depending on the selected modulation, the model performs its calculations based on the fixed power data or interpolates between the two reference points as needed.

6.2 Method of operation

Basically, a cogenerator can be operated in two distinct modes: the heat-driven operation mode and the power-driven operation mode. When operated in the heat-driven operation mode, the cogenerator strictly operates to meet the specified heating energy demand. The electrical energy output is either used to cover self-consumption needs or fed into the public grid. In the power-driven operation mode, the device is operated based on electricity demand. It must, however, be ensured that the heat output may be directly or indirectly decreased at any time by means of appropriate tank modules. Should this not be the case, the surplus heat must be dissipated by means of appropriate emergency cooling devices. This, however, negatively affects the system's overall efficiency and should, therefore, be avoided as far as possible. Thus, an interesting alternative is provided by combined operation, whereby priority is given to meeting the specified heating demand while simultaneously attempting to supply the most possible amount of electrical energy so that no excess heat is dissipated unused to the environment.

In Polysun, the cogenerator's operation mode may be defined by selecting the appropriate control mode. The programmable controller makes it possible to operate the cogenerator both according to heat and electricity demand or based on any combination of these.

6.3 Cogenerator controller

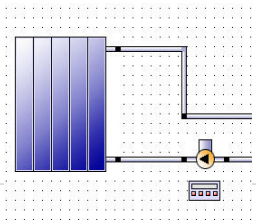
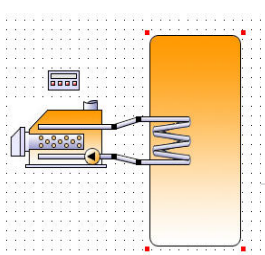
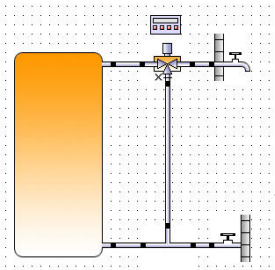
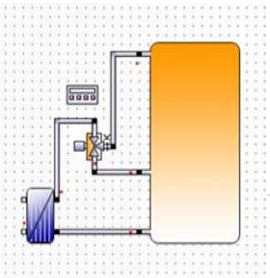
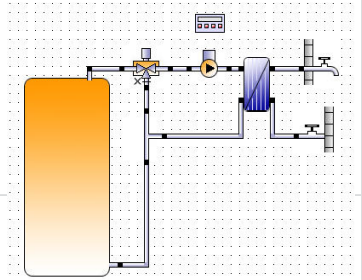
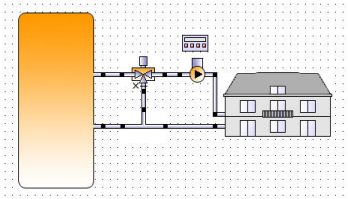
The component "cogenerator" may be operated both through the heat generator controller as well as by means of the programmable controller. It should be noted that for the heat generator controller only (and directly) the heat-driven operation mode is available as a default setting. Alternatively, only the status or additionally the cogenerator's controlled output may be selected

for the corresponding modulating operation. It should also be noted that a cogenerator may only be operated in controlled mode if the relevant reference points have been appropriately parameterized in the database; otherwise, despite the controlled operation having been selected, the cogenerator will not operate in modulating mode.
Next to the control mode, an additional output is available for the programmable controller that may alternatively be set to "1" (heat-driven operation mode) or "2" (power-driven operation mode). As in the preceding case, both the status and the controlled power output must be selected. The control mode allows the user to define whether the requested output is a thermal (1) or electrical (2) output. Accordingly, the model performs its calculations with thermal or electrical values from the database. The third available control mode is the "0" mode. If this is active, the cogenerator will operate in non-modulating mode, even if essentially it could also operate in modulating mode. This makes it possible to study the influence of modulation.

Description	**Control value**	**Additional controller outputs**	**Function description**
Fixed maximum power	0	-	The cogenerator runs at the maximum power level
Heat-driven operation	1	“Controlled power heat generator“	The cogenerator delivers, as far as possible, the desired thermal power set via the “Controlled power heat generator“ controller value. (default mode)
Power-driven operation	2	“Controlled power heat generator“	The cogenerator supplies, as far as possible, the desired electrical power set via the “Controlled power heat generator“ controller value.

7 Controllers

7.1.1 Overview of controllers in Polysun

						
Solar loop controller	The solar loop can be controlled in 4 different ways: 1: Fixed flow rate 2: Specific flow rate per collector field (in l/h/m2 of aperture area) 3: Matched flow 4: Pressure drop according to the pump characteristics					
Variable speed pump controller					The variable speed pump controller controls the flow rate of the primary pump so that the secondary side reaches a certain temperature.	
Auxiliary heating controller		The auxiliary heating controller can be used for internal electric resistance heaters and external boilers. The two output signals are equal and digital. Therefore in certain cases the controller can be used for pumps, too.		x		
Mixing valve controller			The mixing valve controller generates an analogic output signal and mixes two inlet temperatures in order to reach the requested value. The hotter connection must be connected horizontally on the left side of the x, the colder one must be connected vertically at the x.			
Heating circuit controller						The heating circuit controller can be used only to control the pump of the heating circuit.
Temperature controller with AND/OR operation	x	x		The temperature controller with AND/OR operation generates a digital output signal and finds its best application with switching valves. One output signal is calculated based on two temperature levels which can be freely set. It can be also used as a controller for boilers and pumps. Various reference temperatures can be linked logically with AND/OR operations.		
Flow rate controller	x	The flow rate controller provides a digital output signal and can be used to switch on and off a boiler.			The flow rate controller measures a flow rate and passes it on as a pump setting.	
Irradiance controller	The irradiance controller provides a digital output signal based on different radiation intensity values.					

7.1.2 Introduction

In this chapter we will provide an overview of the different controllers available in Polysun and their use and operation.

The following controllers are currently implemented in Polysun:

- Solar loop controller
- Variable speed pump controller
- Auxiliary heating controller
- Mixing valve controller
- Heating circuit controller
- Temperature controller with AND/OR Operation
- Flow rate controller
- Irradiance controller

Controller functions are basically editable at all user levels. Only the Designer level enables the user to individually integrate controllers within hydraulic schemes. Light level users will not be able to edit control outputs. Professional level users are able to edit the control parameters, but not the controller type.

Note:

Controllers employed in Polysun templates are defined as they are normally used in practice. The pre-defined parameter settings do not in any way claim to ensure enhanced solar yields.

7.1.3 Controller selection

Adding a controller (Designer version) in the variant you will be prompted to enter the type of controller in a query dialog:

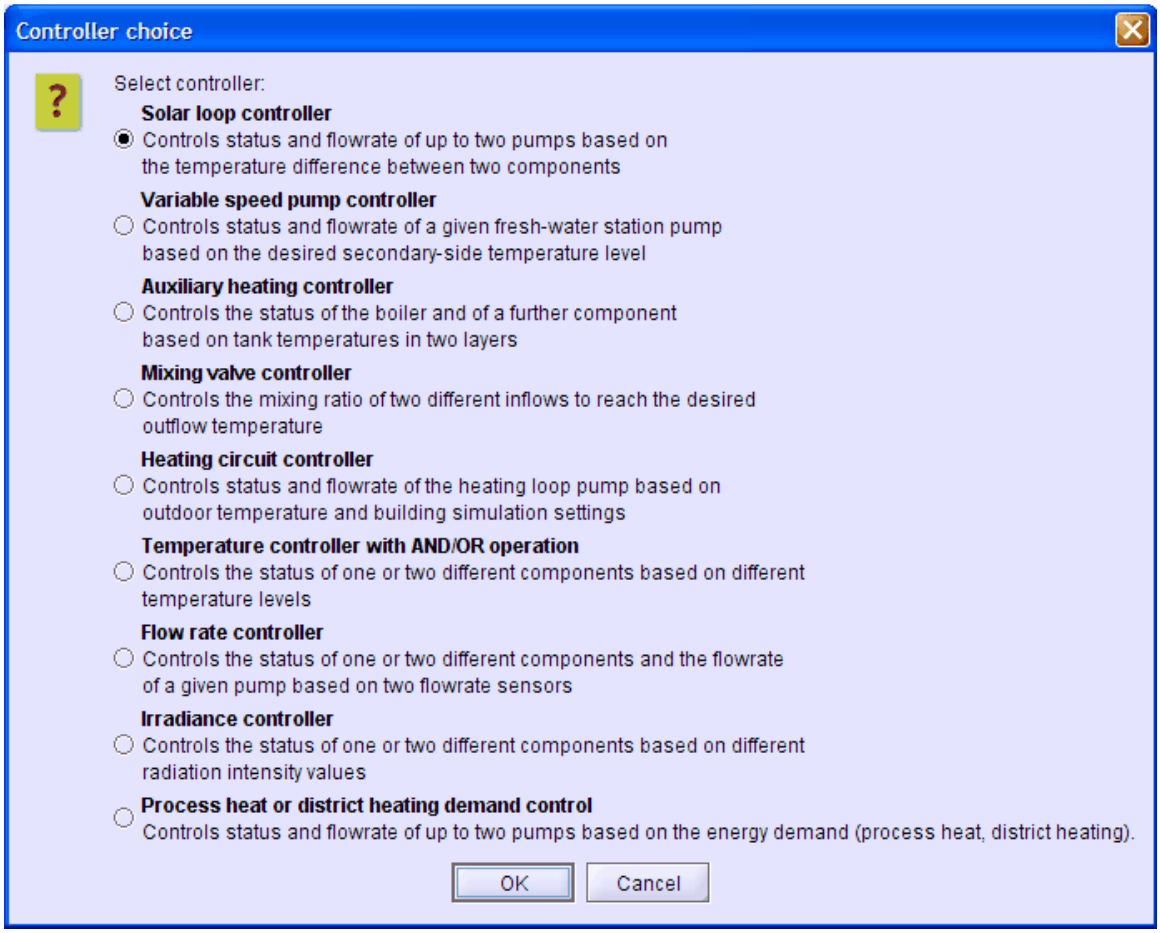

Controller choice
Select controller:
Solar loop controller
Controls status and flowrate of up to two pumps based on the temperature difference between two components
Variable speed pump controller
Controls status and flowrate of a given fresh-water station pump based on the desired secondary-side temperature level
Auxiliary heating controller
Controls the status of the boiler and of a further component based on tank temperatures in two layers
Mixing valve controller
Controls the mixing ratio of two different inflows to reach the desired outflow temperature
Heating circuit controller
Controls status and flowrate of the heating loop pump based on outdoor temperature and building simulation settings
Temperature controller with AND/OR operation
Controls the status of one or two different components based on different temperature levels
Flow rate controller
Controls the status of one or two different components and the flowrate of a given pump based on two flowrate sensors
Irradiance controller
Controls the status of one or two different components based on different radiation intensity values
Process heat or district heating demand control
Controls status and flowrate of up to two pumps based on the energy demand (process heat, district heating).
OK
Cancel

Figure 42: Controller selection

Choose a controller as required by means of the above controller overview. The controllers “temperature“ and “flow rate“ may be used in different applications. Once you’ve added the controller to the system, click on the controller component in the variant and define its features.

In the following chapters we will provide a detailed description of all controllers. The application of the individual controllers is shown in the above table.

In the definition of control features appropriate examples in the templates may be taken into consideration.

7.1.4 General control features

7.1.4.1 Controller “Description“

Entering figures or text in the field “Description“ these will appear after closing and re-opening the window in the title area of the controller:

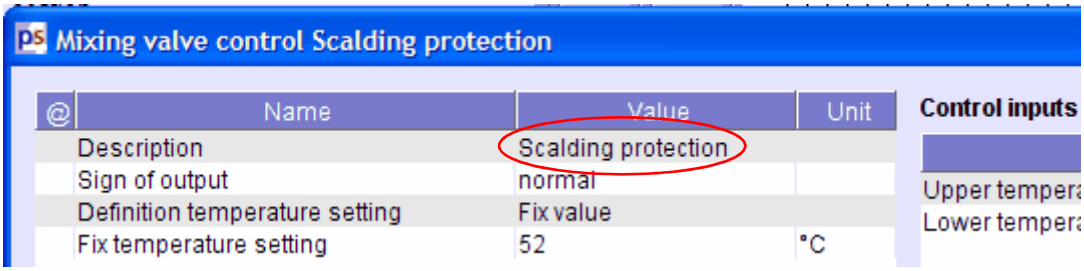


Figure 43: Scalding protection for mixing valve controller

7.1.4.2 Automatic numbering of Polysun:

Adding multiple controllers in Polysun this latter will automatically assign each controller a consecutive number regardless of the fact that previously added controllers were later cancelled. Such consecutive numbers may be edited manually. A resetting of the consecutive numbering is, however, impossible. For each new variant the numbering will automatically start from ”1“.

7.1.4.3 Timer controller

The “timer function“ may be used for all controllers, i.e the user will be able to define availability times in which the controller should be operating. This function enables to enter time, day and month in which the controller should be ”active“ as required. In idle mode outputs are set to zero.

Availability times
Timer
Hourly values file
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Mon Tue Wed Thu Fri Sat Sun
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

Figure 44: Timer controller

The definition of independent ”week and month profiles“ is not possible.

7.1.4.4 Controller outputs

Two parallel outputs are usually available. If two components need to be switched on and off in parallel this may be achieved by means of a special controller. In case of a number of parallel controlled components in excess of two the controller should be copied. An exception is provided by the mixing valve controller that only outputs an analogic signal.

7.1.4.5 “Energy demand not covered“

A number of controllers (e.g.: temperature, flow rate) allow to set fixed and variable temperature settings. Sometimes after running a simulation the energy demand will be shown as ”not covered“. This may happen if the temperature settings or flow rates defined within controllers and user profiles are not reached.

You may, for example, have set a mixing valve controller to ”variable temperature setting: hot water demand“ and entered in the hot water user profile a temperature of 50°C. If the controller was set so that the temperature setting for hot water may not be reached (e.g. due to temperature losses between mixing valve and tap) Polysun will show the report ”Energy demand not covered” once the simulation is over. If this is the case check the state of the different temperature levels and compensate the temperatures in the controllers by means of ”temperature shift“.

If a “Energy demand not covered“ report is shown this does not mean that Polysun is making wrong calculations or that the hydraulic system is not correctly working but that information is only available on whether the entered temperature levels and flow rates were reached. The generated solar yields will be correct also if temperature levels and flow rates were not reached. In this case check the parameters entered in the controllers and the different values against the hourly results of the individual components.

7.1.4.6 Sign of output

Output signals can be digital (0 or 1) or analogic (0…1). If the notation of the employed ratings matches the actual situation (e.g. higher temperature > lower temperature) the output signal will be 1 (“true“). This corresponds to the ”normal“ sign. If an “inverted“ sign is used the output signal will be computed 1-x. In the above example 0 (false) would be the output. Such convention applies to both output signals so long as both were duly defined. If the pump shown in the time window is disabled the output signal will be 0 also in case of inverted choice.

7.1.5 Solar loop controller

The solar loop controller is a two-channel controller that regulates the pump in the solar-loop.

The controller regulates the status and flow rate of up to two pumps based on the temperature difference of two distinct measured values.

The controller has 2 (plus 3 optional) analogic inputs.

The controller has 1 (plus 3 optional) outputs (partially digital and partially analogic).

7.1.5.1 Block diagram

The block diagram shows the employed measuring and controlling values.

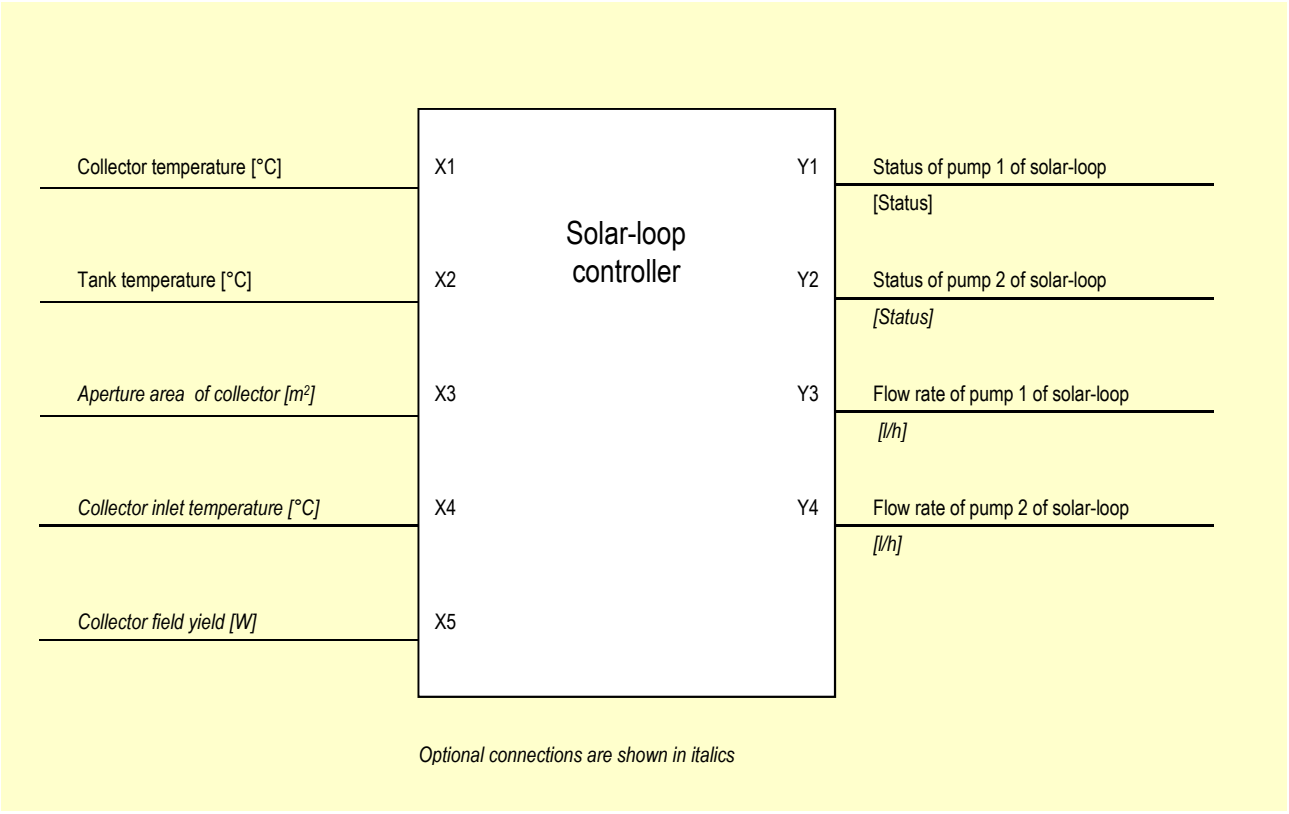


Figure 15: Block diagram: measuring values of solar loop

7.1.5.2 Controller input mask "Fixed flow rate"

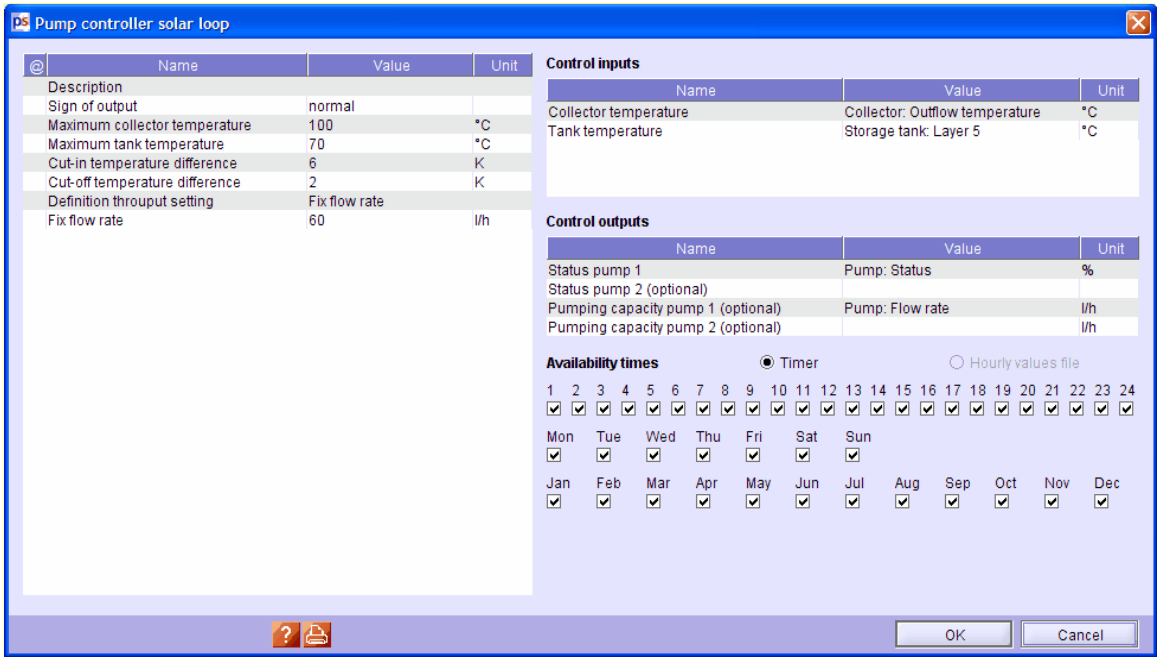


Figure 42: Controller input mask "Fixed flow rate"

With this setting the solar pump cuts in as soon as the collector outflow temperature is 6 degrees higher than the temperature in the tank on layer 5. The flow rate is 60 l/h for the collector field as a whole.

7.1.5.3 Controller input mask ”Specific flow rate“

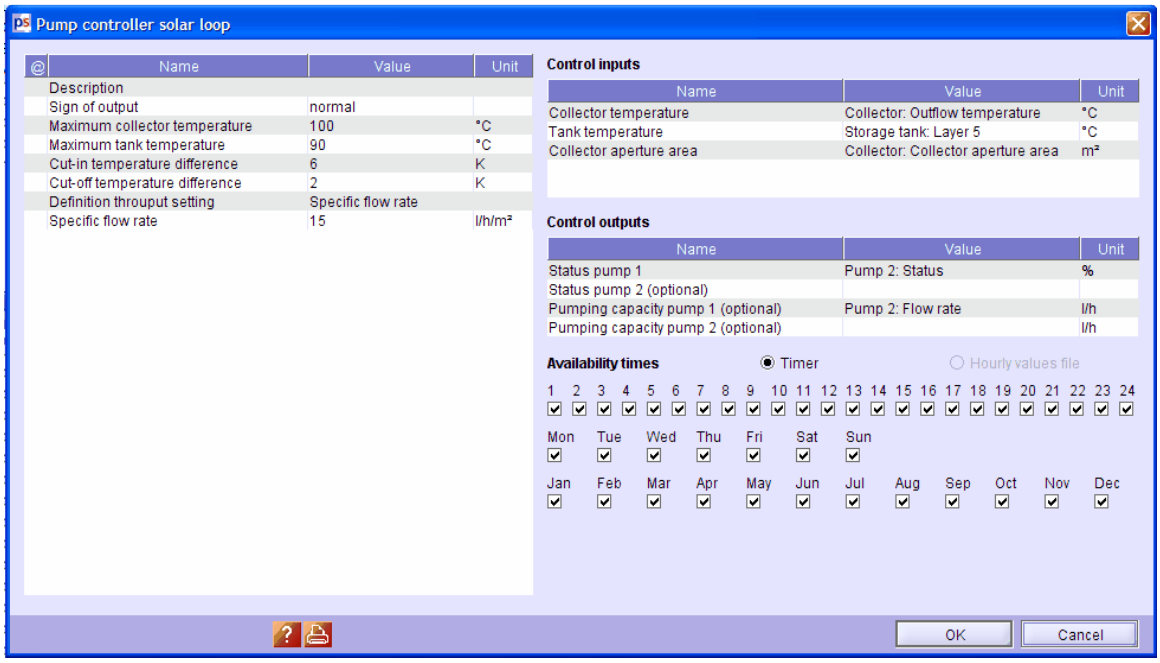


Figure 47: Controller input mask “Specific flow rate“

With this setting the solar pump cuts in as soon as the collector outflow temperature is 6 degrees higher than the temperature in the tank on layer 5. The flow rate is 15 l/h/m2 of collector field.

7.1.5.4 Controller input mask ”Matched flow“

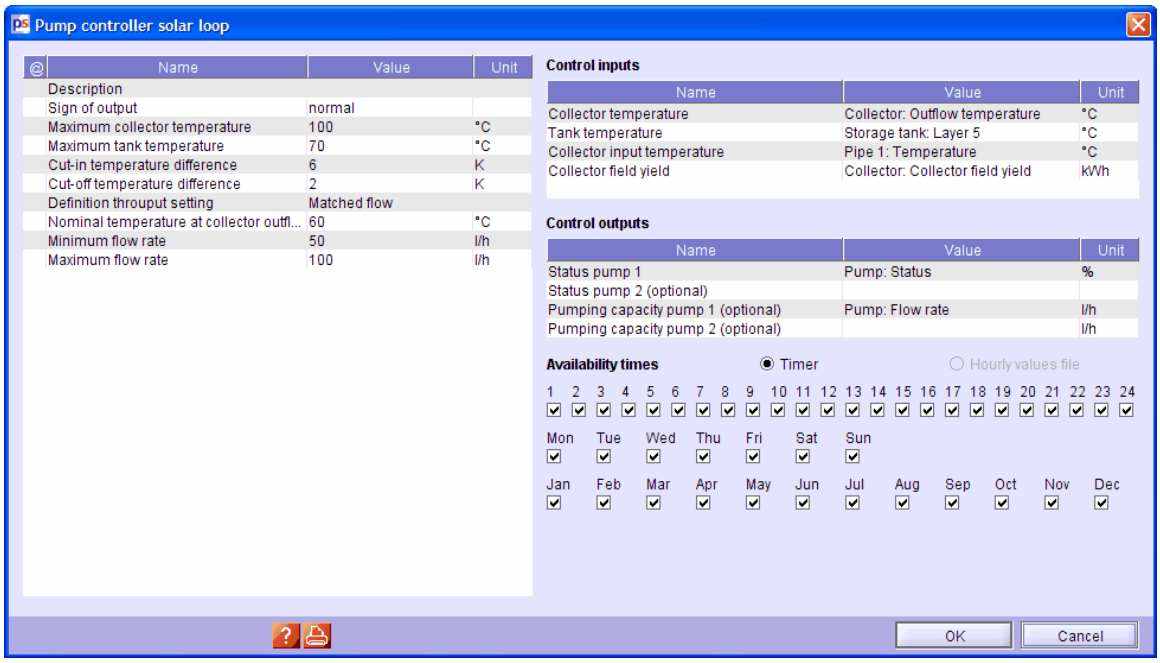


Figure 48: Controller input mask ”Matched flow“

With this setting the solar pump cuts in as soon as the collector outflow temperature is 6 degrees higher than the temperature in the tank on layer 5. The flow rate ranges between 50 and 100 l/h for the collector field as a whole as an attempt is made to reach an output

temperature of 60°C.

Input values

7.1.5.5 Collector temperature [°C]

The value refers to the point where the temperature of the collector is measured. Enter either the collector mean or outflow temperature.

7.1.5.6 Tank temperature [°C]

The value refers to the point where the tank temperature is measured. Enter the relevant tank layer.

7.1.5.7 Aperture area of collector [m^2] (required in case of specific flow rate)

The value refers to the aperture area of the selected collector. This value enables a pump to be controlled with a specific flow rate.
(see the definition of flow rate setting in the control parameters)

7.1.5.8 Inlet temperature of collector [°C] (requir ed in case of matched flow operation)

The collector's inlet temperature is used to define the pump flow rate in "Matched flow" mode. To this end measure pipe temperature at collector's inlet.

7.1.5.9 Yield of collector field [W] (required in case of matched flow operation)

The yield of the collector field is used to define the pump rate in "Matched flow" mode. Select the relevant collector field.

Description of control parameters

7.1.5.10 Description

The "description" value enables the user to assign controllers any name or number. Polysun assigns a consecutive number as a standard feature as different controllers are added chronologically in the hydraulic system.

7.1.5.11 Sign of output

The term "Normal" means that digital output signals are controlled as intended in the switching logics. (Example: if X1>X2 the output of pump 1 is positive)
The term "Inverted" that output signals are multiplied -1.
(Example: if X1>X2 the output of pump 1 is equal to zero)

7.1.5.12 Maximum temperature of collector [°C]

If collector temperature X1 is higher than the entered maximum temperature the solar-loop pump cuts off.

7.1.5.13 Maximum temperature of tank [°C]

If tank temperature X2 is higher than the entered maximum temperature the solar-loop pump cuts off.

7.1.5.14 Cut-in temperature difference [K]

If the collector outflow temperature X1 is higher than tank temperature X2 by the entered value, the solar-loop pump cuts in.
(Example: if X1 > X2 + value, the pump cuts in)

7.1.5.15 Cut-off temperature difference [K]

If the collector outflow temperature X1 is lower than tank temperature X2 plus the entered value, the solar-loop pump cuts off.
(Example: if X1 < X2 + value, the pump cuts off)

7.1.5.16 Definition of flow rate setting

- Specific flow rate
  The controller regulates the pump according to the aperture area of the collector field by means of the value entered in the "Specific Flow rate". **The corresponding pumps should be set to "Flow rate setting"** (Double-click on pump to adjust the required settings)**.**
- Fixed flow rate
  Selecting a fixed flow rate the pump is controlled by means of the value entered in the "Fixed flow rate" field. The input value "Aperture area of collector" has no relevance and will be hidden. **The corresponding pumps should be set to "Flow rate setting"** (Double-click on pump to adjust the required settings)**.**
- Matched Flow
  In case of "matched flow" operation the flow rate of the pump will be defined by means of a preset flow rate range. In the process the flow rate will be set so as to allow the collector output temperature to be reached. **The corresponding pumps should be set to "Flow rate setting"** (Double-click on pump to adjust the required settings)**.**

7.1.5.17 Definition of flow rate value

- Specific flow rate [l/h/m^2]
  Value of the specific flow rate in [l/h/m^2] aperture area of collector field.
- Fixed flow rate [l/h]
  Value of the required fixed flow rate of collector field.
- Matched flow:
  Value used to define the variable flow rate: collector outflow temperature [°C]; minimum flow rate [l/h], maximum flow rate [l/h].

Output values

7.1.5.18 Status Pump 1

This digital output refers to the solar-loop pump to be controlled. Select the relevant pump from the list.

7.1.5.19 Status Pump 2 (Optional)

This digital output is activated just like the output of Status Pump 1. A second component (e.g. a further pump) may be controlled based on the same criteria as

Status Pump 1. Select the relevant component from the list.

7.1.5.20 Flow rate Pump 1 (Optional)

This analogic output controls the flow rate of pump 1. Select the relevant pump from the list. (the output is active only if the option "Flow rate setting" has been selected in the field "Flow rate-controlled" for the pump to be controlled; otherwise pump settings will have priority over the analogic control outputs. Double click on the pump to change/check the settings)

7.1.5.21 Flow rate Pump 2 (Optional)

This analogic output performs the same function as the flow rate output of pump 1. Select the relevant pump from the list.

7.1.5.22 Overview of control-dependences

Outputs	Parameter	Tip	Inputs	Function
Y1: Status Pump 1 Y1 = Y2 Y2: Status Pump 2	Fixed flow rate	*Set pump to* *- Flow rate setting -*	X1: Collector temperature	Y1=0 if X1 > maximum collector temperature [°C]
			X2: Tank temperature	Y1=0 if X2 > maximum tank temperature [°C]
			X1: Collector temperature	Y1=1 if X1 > X2 + cut-in temperature difference [K] Y1=0 if X1 < X2 + cut-off temperature difference [K]
			X2: Tank temperature	
Y3: Flow rate Pump 1 Y3 = Y4 Y4: Flow rate Pump 2	Specific flow rate	*Set pump to* *- Flow rate setting –* *Flow rate dependent on X3 and the value of the specific flow rate*	X1: Collector temperature	Y1=0 if X1 > maximum collector temperature [°C]
			X2: Tank temperature	Y1=0 if X2 > maximum tank temperature [°C]
			X1: Collector temperature	Y1=1 if X1 > X2 + cut-in temperature difference [K] Y1=0 if X1 < X2 + cut-off temperature difference [K]
			X2: Tank temperature	
			X3: Aperture area of collector	
Y3: Flow rate Pump 1 Y3 = Y4 Y4: Flow rate Pump 2	Matched Flow	*Set pump to* *- Flow rate setting –* *Flow rate within the entered range and adjusted to the defined collector output temperature*	X1: Collector temperature	Y1=0 if X1 > maximum collector temperature [°C]
			X2: Tank temperature	Y1=0 if X2 > maximum tank temperature [°C]
			X1: Collector temperature	Y1=1 if X1 > X2 + cut-in temperature difference [K] Y1=0 if X1 < X2 + cut-off temperature difference [K]
			X2: Tank temperature	
			X4: Collector input temperature	
			X2: Yield of collector field	

7.1.6 Variable speed pump controller

The variable-speed pump controller is a two-channel controller regulating status and flow rate of the pump of the fresh-water station.

The controller has 4 (plus 2 optional) analogic inputs.

The controller has 2 digital and analogic outputs.

7.1.6.1 Block diagram

The block diagram shows the employed measuring and controlling values

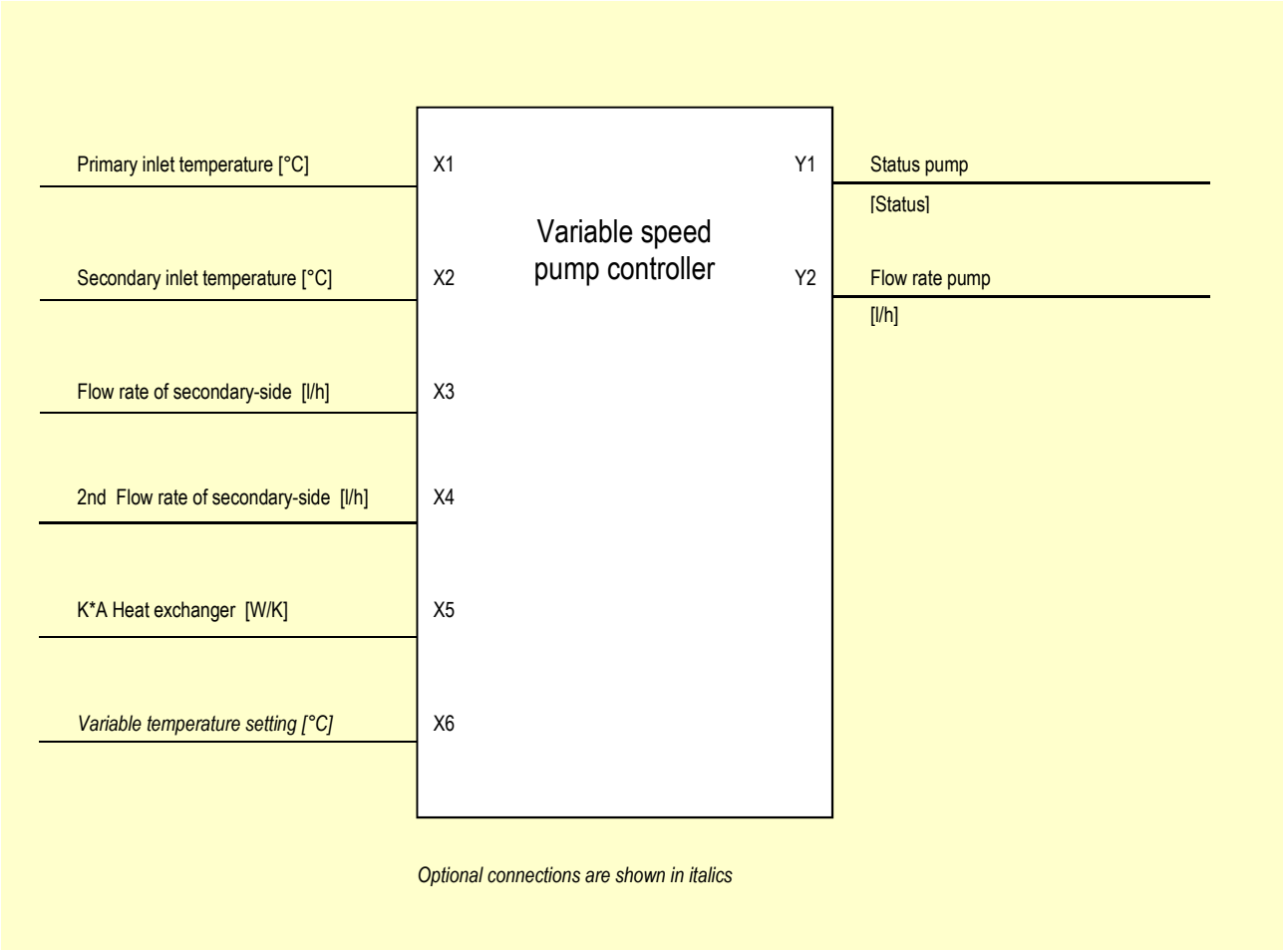


Figure 49: Block diagram: measuring values of variable speed pump controller

7.1.6.2 Controller input mask ”Fixed temperature setting“

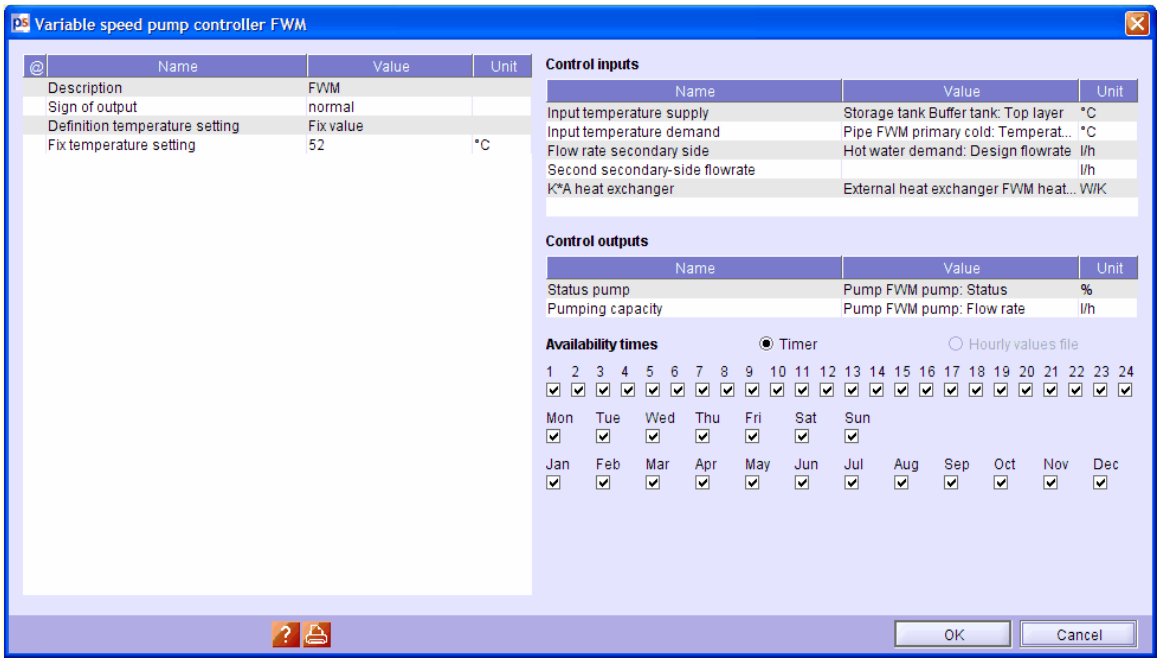


Figure 50: Controller input mask “Fixed temperature setting“

With this setting the pump of the fresh-water station cuts in as soon as hot water is tapped. Pump speed is adjusted so that the output temperature on the secondary-side can reach 52°C.

7.1.6.3 Controller input mask ”Variable temperature setting“

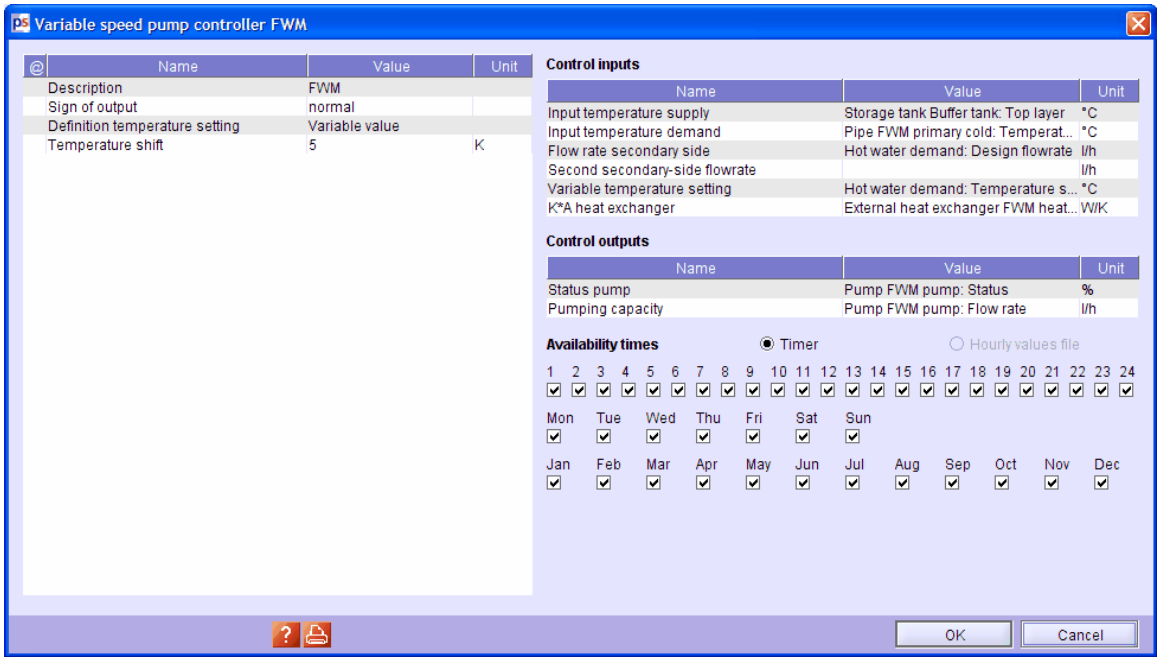


Figure 51: Controller input mask “Variable temperature setting“

With this setting the pump of the fresh-water station cuts in as soon as hot water is

tapped. Pump speed is adjusted so that the output temperature on the secondary-side is as high as the hot water demand temperature setting plus 5°C.

Input values

7.1.6.4 Inlet temperature of primary side [°C]

The value shows the point where the inlet temperature of the primary side is measured. Enter pipe temperature immediately before the plate heat exchanger or, e.g., the temperature of the tank connection.

7.1.6.5 Inlet temperature of secondary side [°C]

The value shows the point where the inlet temperature of the secondary side is measured. Enter cold water temperature or pipe temperature immediately before the plate heat exchanger of secondary side.

7.1.6.6 Flow rate of secondary side [l/h]

The value refers to the flow rate of the reference side. In fresh-water modules the value refers to the nominal flow rate of hot water withdrawal.

7.1.6.7 Second flow rate of secondary side [l/h]

As in flow rate of secondary-side a second flow rate may be entered. In case of the fresh-water station with circulation it is the circulation flow rate.

*7.1.6.8 K*A Plate heat exchanger [W/K]*

This value refers to the heat transfer properties and the heat transfer surface of the heat exchanger. Data are defined by the manufacturer.

7.1.6.9 Variable temperature setting [°C] (optional)

The temperature that should be reached at the outflow of the plate heat exchanger, e.g. the temperature setting of the hot water demand.

Description of control parameters

7.1.6.10 Description

The “description“ value enables the user to assign controllers any name of number. Polysun assigns a consecutive number as a standard feature as different controllers are added chronologically in the hydraulic system.

7.1.6.11 Sign of output

The term “Normal“ means that digital output signals are controlled as intended in the switching logics. (Example: if X3+X4>0 the output of pump 1 is positive)
The term “Inverted” that the digital output signals are multiplied -1.

7.1.6.12 Definition of temperature setting

- Fixed temperature setting
  The components connected to the controller are adjusted so that the entered fixed temperature setting can be reached at the output of the plate heat exchanger on the secondary side.
- Variable temperature setting
  The components connected to the controller are adjusted so that the entered variable temperature setting can be reached at the output of the plate heat exchanger on the secondary side allowing for the relevant temperature shift.

7.1.6.13 Definition of temperature shift

- For example. 5 [K]
  The temperature shift value enables to adjust temperature drops in the plate heat exchanger and pipe cooling after the plate heat exchanger. If the value is positive the outflow temperature will be increased by this value. If the value is negative the outflow temperature will be decreased by this value.

Output values

7.1.6.14 Pump Status [%]

This digital output refers to the pump to be controlled, e.g. the pump of the fresh-water station. Select the relevant pump from the list.

7.1.6.15 Pump Flow rate [l/h]

This analogic output adjusts the pump flow rate so that the desired temperature level can be reached on the secondary side of the plate heat exchanger. In the process the plate heat exchanger shows a temperature drop from the primary to the secondary side. This temperature drop may be corrected through the temperature shift.

The output is active only if the option "Flow rate setting" has been selected in the field "Flow rate controlled" for the pump to be controlled; otherwise pump settings will have priority over the analogic control outputs. Double click on the pump to change/check the settings.

Select the relevant pump from the list.

Overview of control-dependences

Outputs	Parameter	Tip	Inputs	Function
Y1: Pump Status Y2: Pump flow rate	Fixed temperature setting	*Adjust pump to* *- Flow rate settings -*	X1: Primary-side inlet temperature [°C] X2: Secondary-side inlet temperature [°C] X3: Secondary-side flow rate [l/h] X4: Second flow rate of secondary-side [l/h] X5: K*A Plate heat exchanger[W/K]	Y1=0 if X3 + X4 = 0 Y1=1 if X3 + X4 > 0 Y2= f(X1, X2, X3 + X4, X5)
Y1: Pump Status Y2: Pump flow rate	Variable temperature setting	*Adjust pump to* *- Flow rate settings -*	X1: Primary-side inlet temperature [°C] X2: Secondary-side inlet temperature [°C] X3: Secondary-side flow rate [l/h] X4: Second flow rate of secondary-side [l/h] X5: Variable temperature setting [°C] X6: K*A Plate heat exchanger [W/K]	Y1=0 if X3 + X4 = 0 Y1=1 if X3 + X4 > 0 Y2= f(X1, X2, X3 + X4, X5, X6)

7.1.7 Auxiliary heating controller

The auxiliary heating controller is a two-channel controller that regulates status and flow rate of the boiler and the status of a further component based on tank temperatures in two layers.

The controller has 2 analogic inputs.

The controller has 1 (plus 1 optional) digital output.

A switch is turned on based on the temperature of a given point and turned back off based on the temperature of (another potential) point.

7.1.7.1 Block diagram

The block diagram shows the employed measuring and controlling values

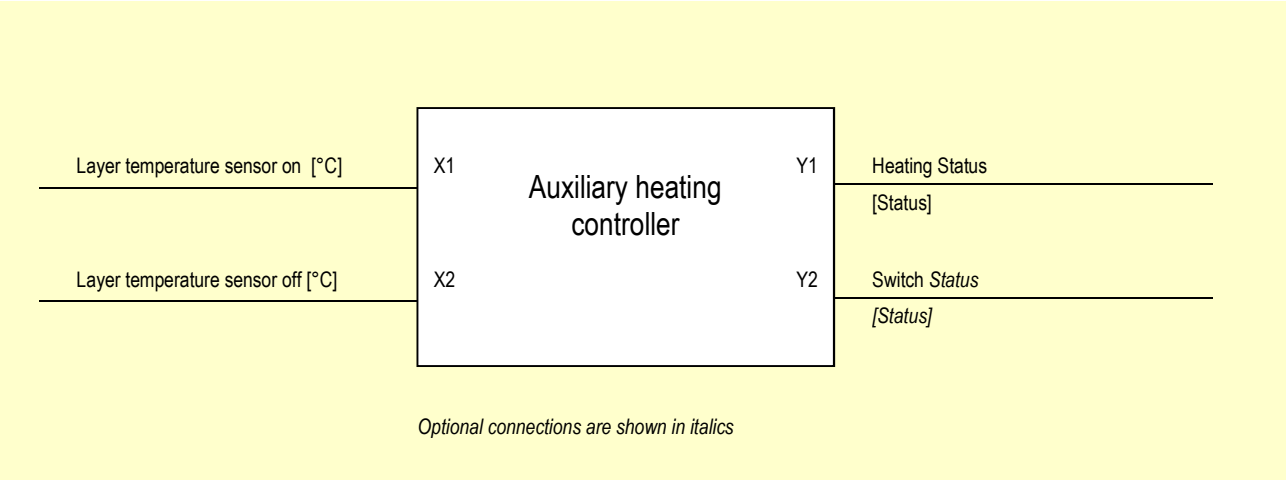


Figure 52: Block diagram: measuring values of auxiliary heating controller

7.1.7.2 Controller input mask

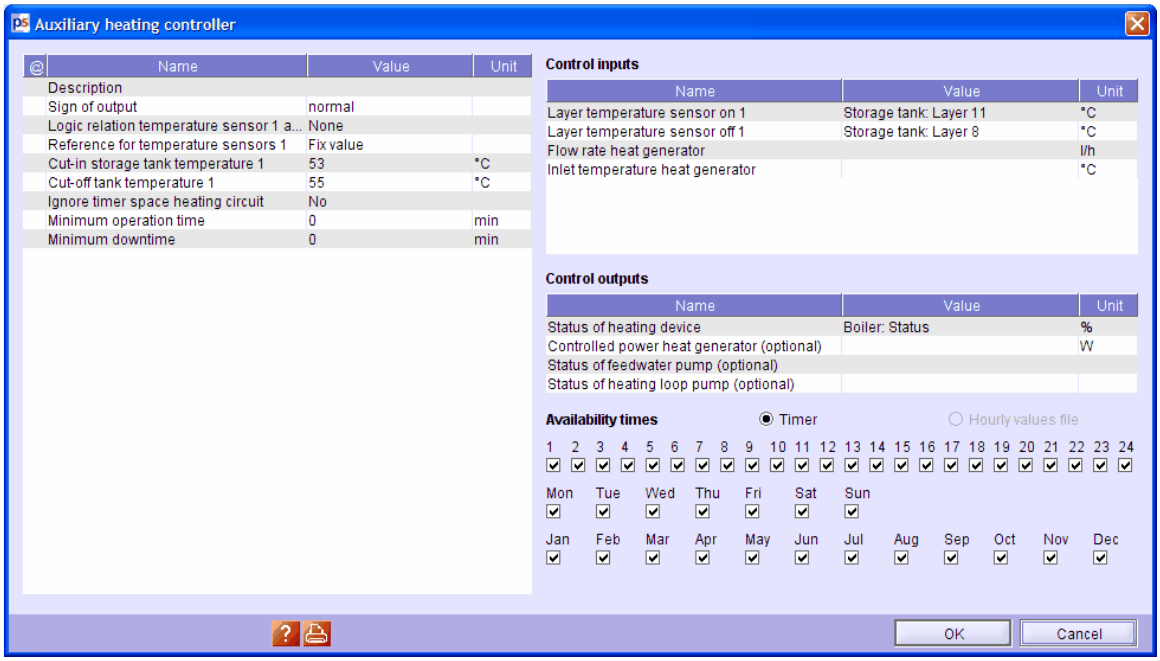


Figure 53: Input mask auxiliary heating controller

With this setting the auxiliary heating cuts in as soon as layer temperature 11 in the tank drops below 53°C.

Input values

7.1.7.3 Layer temperature sensor on [°C]

The value refers to the tank layer in which the temperature is measured to switch on the heating. Select the relevant tank layer.

7.1.7.4 Layer temperature sensor off [°C]

The value refers to the tank layer in which the temperature is measured to switch off the heating. Select the relevant tank layer.

Description of control parameters

7.1.7.5 Description

The “description“ value enables the user to assign controllers any name of number. Polysun assigns a consecutive number as a standard feature as different controllers are added chronologically in the hydraulic system.

7.1.7.6 Sign of output

The term “Normal“ means that digital output signals are controlled as intended in the switching logics. (Example: if X1< cut-in tank temperature the output of pump 1 is positive)
The term “Inverted” that output signals are multiplied -1.

7.1.7.7 Cut-in tank temperature [°C]

Enter the temperature at which the heating should be turned on.

7.1.7.8 Cut-off tank temperature [°C]

Enter the temperature at which the heating should be turned off.

Output values

7.1.7.9 Heating Status

This digital output refers to the heating to be controlled. Select the relevant boiler from the list.

7.1.7.10 Switch Status (Optional)

This digital output enables, if required, to control one further component, for example a second heating, pump or a switching valve. Select the relevant component from the list. This will only allow you to control the status of a given component.

Overview of control-dependences

Outputs	Parameter	Tip	Inputs	Function
Y1: heating status Y1 = Y2 Y2: switch status	---	*Adjust heating to:* *- Fixed power* *- controlled power* *- controlled temperature*	X1: Layer temperature sensor on [°C]	Y1=1 if X1 < Cut-in tank temperature [°C] Y1=0 if X2 > Cut-off tank temperature [°C]
			X2: Layer temperature sensor off [°C]	

7.1.8 Mixing valve controller

The mixing valve controller is a one-channel controller that regulates the mixing ratio of two different inflows so that the desired outflow temperature can be reached. Such outflow temperature may be specified through a constant or variable value. This analogic output enables to control a three-way valve and put in place this way a scalding protection.

The controller has 2 (plus 1 optional) analogic inputs.

The controller has 1 analogic output.

Remark: as during a simulation time step the mixing ratio remains constant its calculation should be based on temperatures that are as constant as possible. You can therefore beneficially use to this end the large volumes preceding the mixer and not the immediately adjacent pipes (for example temperature in tank layers or connections).

7.1.8.1 Block diagram

The block diagram shows the employed measuring and controlling values

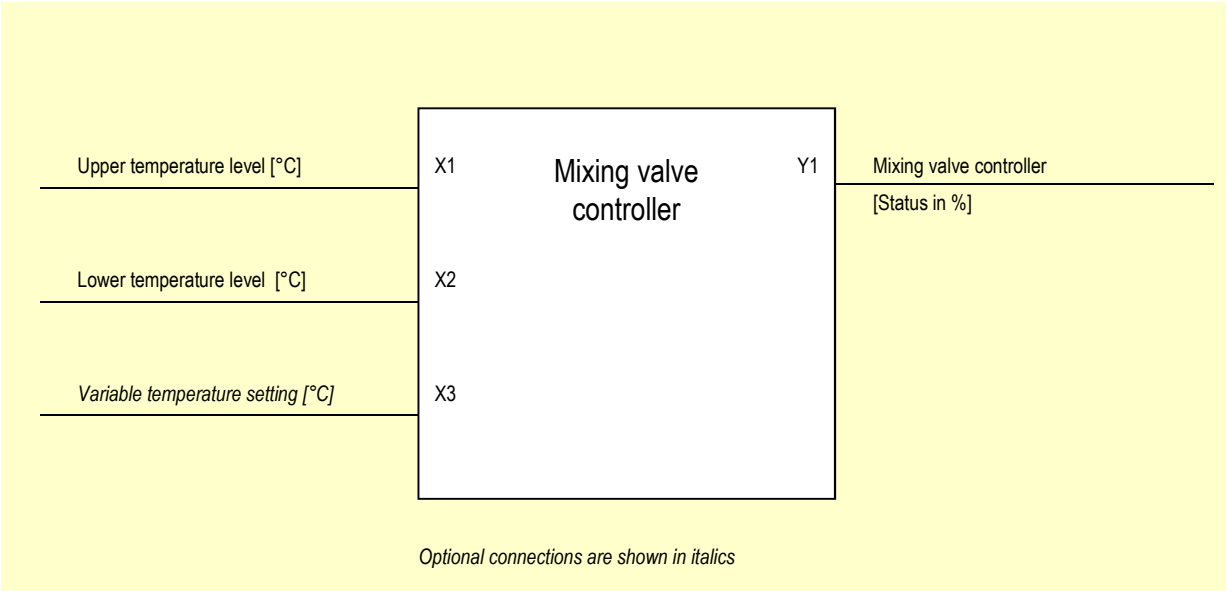


Figure 54: Block diagram: measuring and controlling values of mixing valve control

7.1.8.2 Definition of mixing valve

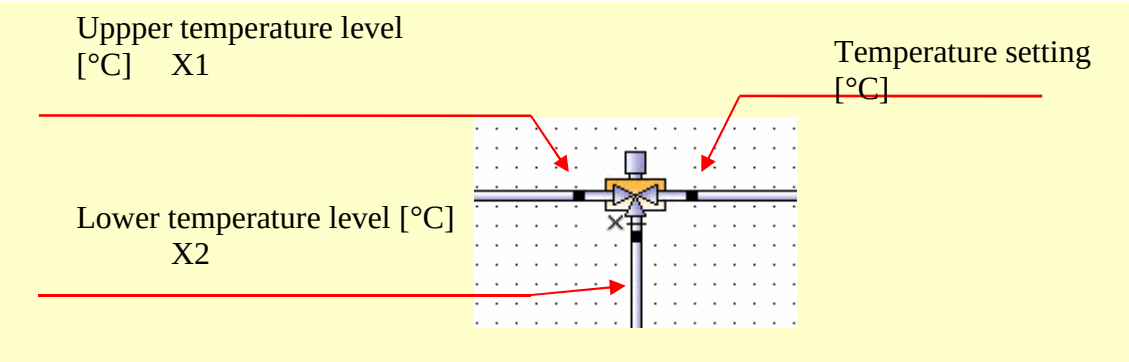


Figure 55:Definition of mixing valve

7.1.8.3 Controller input mask “Fixed value“

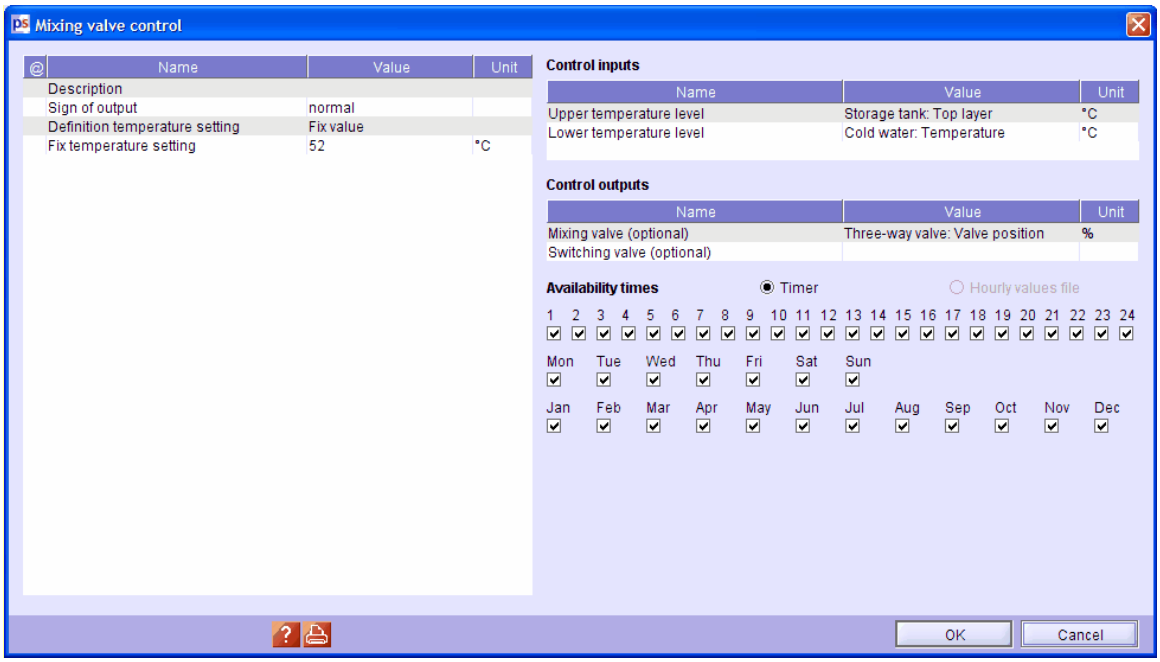


Figure 36: Controller input mask “Fixed value“

Controller input mask ”Variable value“

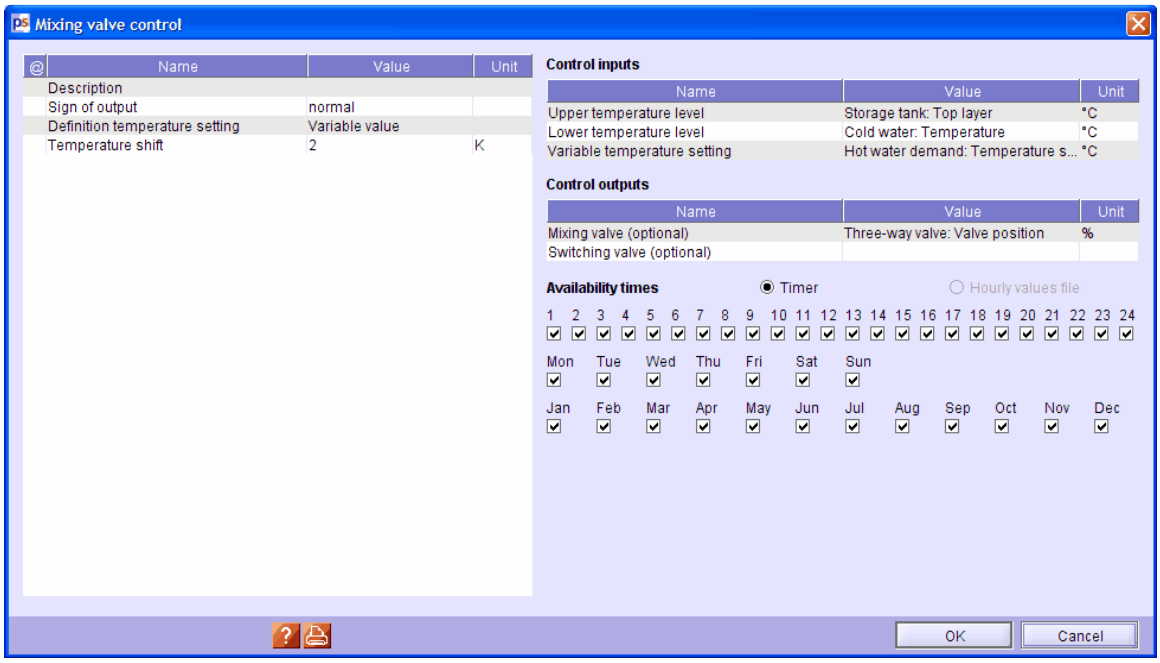


Figure 57: Controller input mask ”Variable value“

With this setting the mixing will be performed based on the variable temperature setting “Hot water demand: temperature setting“ plus 2°K according to the selection of the temperature shift. The hot water temperature setting will be defined in the user profile of the project overview. The temperature shift will enable to compensate the temperature drop between mixing valve outflow and hot water tap.

Input values

7.1.8.4 Upper temperature level [℃]

The value refers to the component in which the upper temperature level is measured. Select the relevant inlet pipe to the mixing valve or the **previous tank connection**.

7.1.8.5 Lower temperature level [℃]

The value refers to the component in which the lower temperature level is measured. Select the relevant pipe to the mixing valve on “Input X“ (see figure ”Definition of mixing valve“)

7.1.8.6 Variable temperature setting [℃] (optional)

The value refers to the temperature setting to be achieved.

Description of control parameters

7.1.8.7 Description

The “description“ value enables the user to assign controllers any name of number. Polysun assigns a consecutive number as a standard feature as different controllers are added chronologically in the hydraulic system

7.1.8.8 Sign of output

The term “Normal“ means that digital output signals are controlled as intended in the switching logics.
“Inverted“ should not be used.

7.1.8.9 Definition of temperature setting

- Fixed value
  The mixing valve will be regulated by means of the measured inlet temperatures so that the specified “Fixed value“ temperature may be reached at the outflow of the mixing valve.
- Variable temperature setting
  The mixing valve will be regulated by means of the measured inlet temperatures so that the specified “Variable value“ temperature may be reached at the outflow of the mixing valve allowing for the temperature shift.

7.1.8.10 Definition of temperature shift

- E.g. 5 [K]
  The temperature shift value enables to compensate the temperature drop between the outflow of the mixing valve and the hot water tap. If the value is positive the outflow temperature will be increased by this value. If the value is negative the outflow temperature will be reduced by such value.

Output values

7.1.8.11 Mixing valve position

The output “Mixing valve“ allows to define the position of the valve. The output regulates the branching ratio of inputs so that the specified temperature setting may be reached.

Overview of control-dependences

Outputs	Parameter	Tip	Inputs	Function
Y1: Mixing valve status	Fixed value	*Adjust mixing valve to - controlled value*	X1: Upper temperature level [°C]	Y1=f(X1,X2) for the specified temperature setting
			X2: Lower temperature level [°C]	
Y1: Mixing valve status	Variable temperature setting	*Adjust mixing valve to - controlled value*	X1: Upper temperature level [°C]	Y1=f(X1,X2,X3) for the specified measured value of variable temperature setting plus temperature shift
			X2: Lower temperature level [°C]	
			X3: Variable temperature setting [°C]	

7.1.8.12 Valve used as switching valve

The switching valve can be operated in the easiest possible manner through the temperature controller.

The mixing valve controller is not suitable for this use.

The switching valve should be connected so that the directions of flow match the figure.

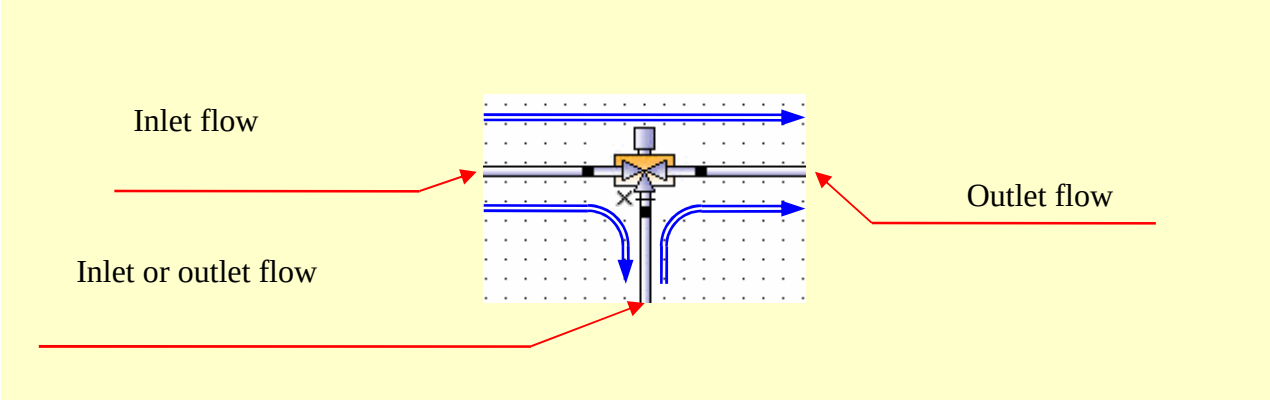


Figure 58: Valve used as switching valve

7.1.9 Heating controller

The heating controller regulates the status and flow rate of a pump based on building simulation settings. Optionally, the controller can also control a mixing valve.

The controller has 4 (plus 3 optional) analogic inputs.

The controller has 2 (plus 2 optional) outputs, partially digital, partially analogic.

Heating loop cut-in and cut-off are based on thermostatic room temperature control. The inlet temperature is calculated based on the outdoor temperature which, in turn, is used as the temperature setting for the mixing valve.

Block-diagram

The block diagram shows the employed measuring and controlling values.

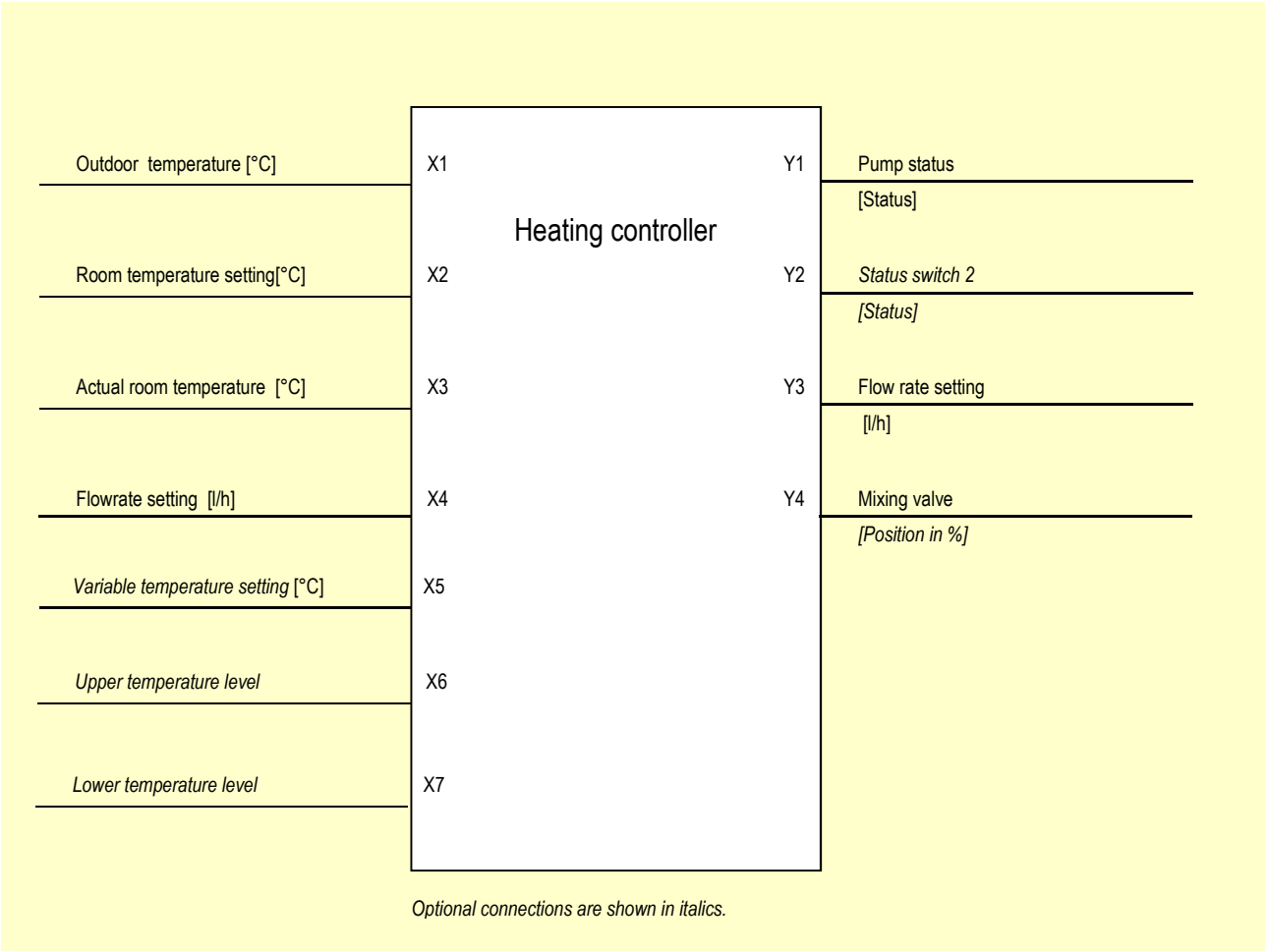


Figure 58: Block diagram: measuring and controlling values of heating controller

Controller input mask

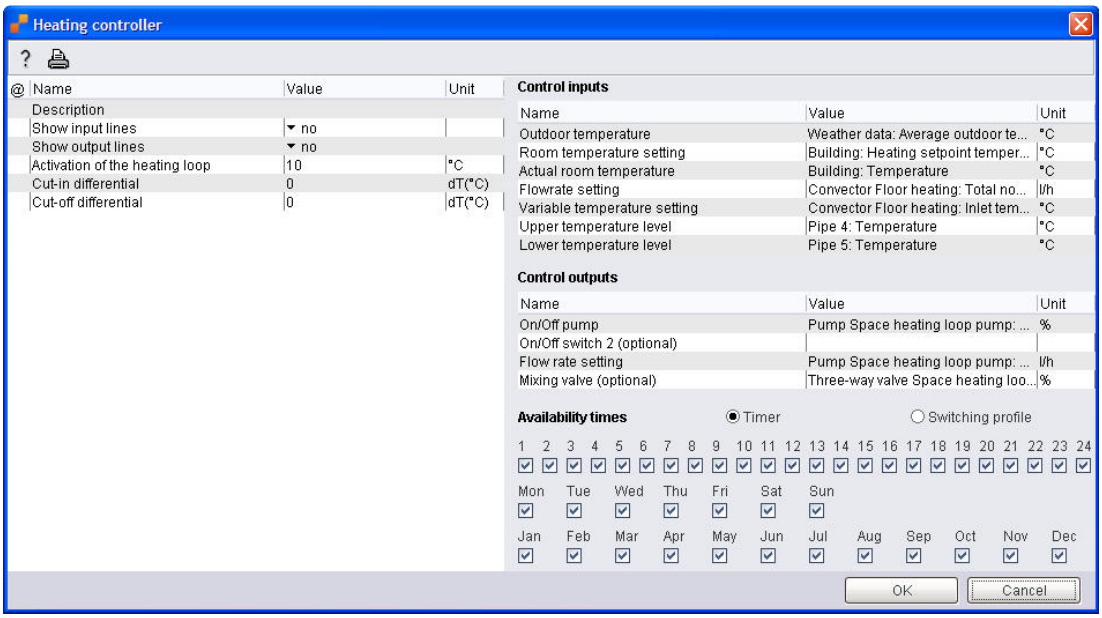


Figure 59: Controller input mask

Input values

7.1.9.1 Outdoor temperature [℃]

The value refers to the weather data being measured. Enter either the weather data outdoor temperature or the 24-h mean outdoor temperature.

7.1.9.2 Room temperature setting [℃]

The value shows how high the room temperature setting is when people are present.

7.1.9.3 Actual room temperature [℃]

The value shows how high the actual average room temperature is.

7.1.9.4 Flow rate settings [l/h]

The value shows the flow rate of the connected convectors. Enter the “Total design flow rate“ for the convector. This will be calculated from the convector properties stored in the catalogue and the number of existing convectors.

7.1.9.5 Variable temperature setting (required for mixing valve)

Enter the inlet temperature setting for the convector. This value determines the maximum inlet temperature.

7.1.9.6 Upper temperature level (required for mixing valve)

The value shows which components the upper temperature level for the mixing valve is being measured in. Select the appropriate inlet pipe to the mixing valve or **the appropriate port on the tank** (as shown in the Mixing Valve Controller section).

7.1.9.7 Lower temperature level (required for mixing valve)

The value shows which components the lower temperature level for the mixing valve is being measured in. Select the appropriate pipe to the mixing valve on ”Input X“ (as shown in the Mixing Valve Controller section).

Description of control parameters

7.1.9.8 Description

The ”description“ value enables the user to assign the controller any name or number. Polysun assigns a consecutive number as a standard feature as different controllers are added chronologically in the hydraulic system

7.1.9.9 Sign of output

The term “Normal“ means that digital output signals are controlled as intended in the switching logics. The term “Inverted“ means that the digital output signals are multiplied by -1.

7.1.9.10 Heating loop activation [°C]

If the outdoor temperature drops below the specified value, the inlet temperature is calculated by means of the outdoor temperature and the inlet temperature setting. If the outdoor temperature exceeds the specified value, the inlet temperature is set to a minimum value.

7.1.9.11 Cut-in hysteresis

The pump in the heating circuit cuts in if the actual room temperature lies below the room temperature setting plus the cut-in hysteresis.

7.1.9.12 Cut-off hysteresis

The pump in the heating circuit cuts off if the actual room temperature lies above the room temperature setting plus the cut-off hysteresis.

Output values

7.1.9.13 Status Pump 1

This digital output refers to the pump to be controlled within the heating loop. Select the relevant pump from the list.

7.1.9.14 Status Switch 2 (Optional)

This digital output is activated just like the Status Pump 1 output. This output enables to control an additional component. For the switching valve “logically one“ means that the output “X“ on the mixing valve is open. Select the relevant component from the list as required.

7.1.9.15 Flow rate setting

Here, the value indicated for “Flow rate“ is transferred to the pump. To this end, select the flow rate of the relevant pump.

This output is only active if the option "Flow rate setting" has been selected in the field "Flow rate controlled" for the pump to be controlled; otherwise the pump settings will have priority over the analogue control outputs. Double click on the pump to check/change settings.

7.1.9.16 Mixing valve (optional)

The required inlet temperature is calculated and the position of the mixing valve is accordingly regulated based on the outdoor temperature and the inlet temperature of the convector. The calculated inlet temperature ranges from a maximum equal to the inlet temperature setting and a minimum equal to the room temperature setting plus 10°C.

Overview of control-dependences

Outputs	Parameter	Tip	Inputs	Function
Y1: Pump status Y1 = Y2 Y2: Status Switch 2	Without mixing valve	*Adjust pump to* *- Flow rate setting*	X1: outdoor temperature X2: room temperature setting X3: actual room temperature X4: Flow rate setting	Y1=0 if X3 > X2 + cut-off hysteresis [°C] Y1=1 if X3 < X2 + cut-in hysteresis [°C]
Y3: Flow rate setting				Y3 = flow rate setting X4
Y1: Pump status Y1 = Y2 Y2: Status Switch 2	With mixing valve	*Adjust pump to* *- flow rate setting* *Adjust mixing valve to set value*	X1: Outdoor temperature X2: Room temperature setting X3: Actual room temperature X4: Flow rate setting X5: Variable temperature setting X6: Upper temperature level X7: Lower temperature level	Y1=0 if X3 > X2 + cut-off hysteresis [°C] Y1=1 if X3 < X2 + cut-in hysteresis [°C]

7.1.10 Temperature controller with AND/OR operation

The temperature controller regulates the status of up to two components based on one or two temperature differences. The controller may be used for different components including the switching valve (see chapter “Mixing valve controller”)

The controller has 1 (plus 3 optional) analogic inputs.

The controller has 1 (plus 1 optional) digital outputs.

The switch cuts-in or off based on the comparison of two or four different temperatures. The comparison may be carried out with a constant value; if several temperature sensors are used the different measured temperatures will be compared with one another.

7.1.10.1 Block diagram

The block diagram shows the employed measuring and controlling values

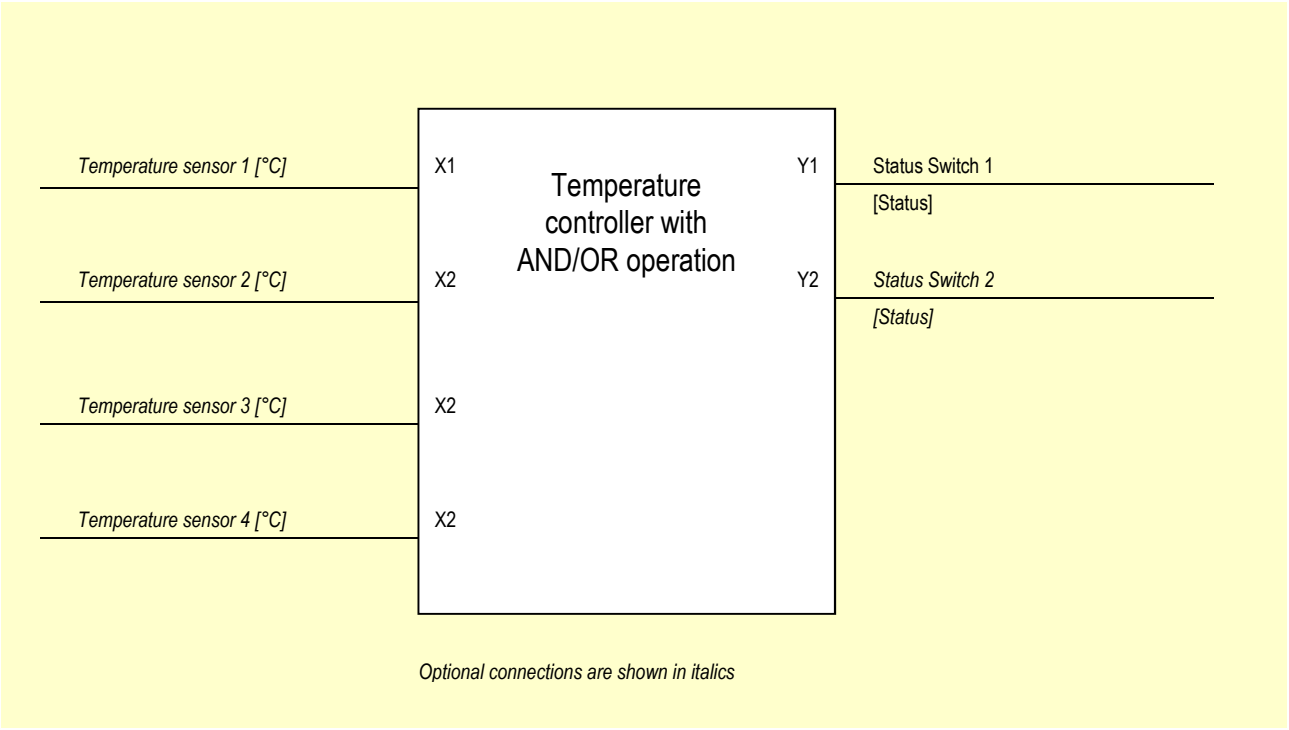


Figure 62: Block diagram: measuring and controlling values of temperature controller with AND/OR operation

7.1.10.2 Controller input mask without logical connection once with ”Fixed value“ and once with ”Variable value“

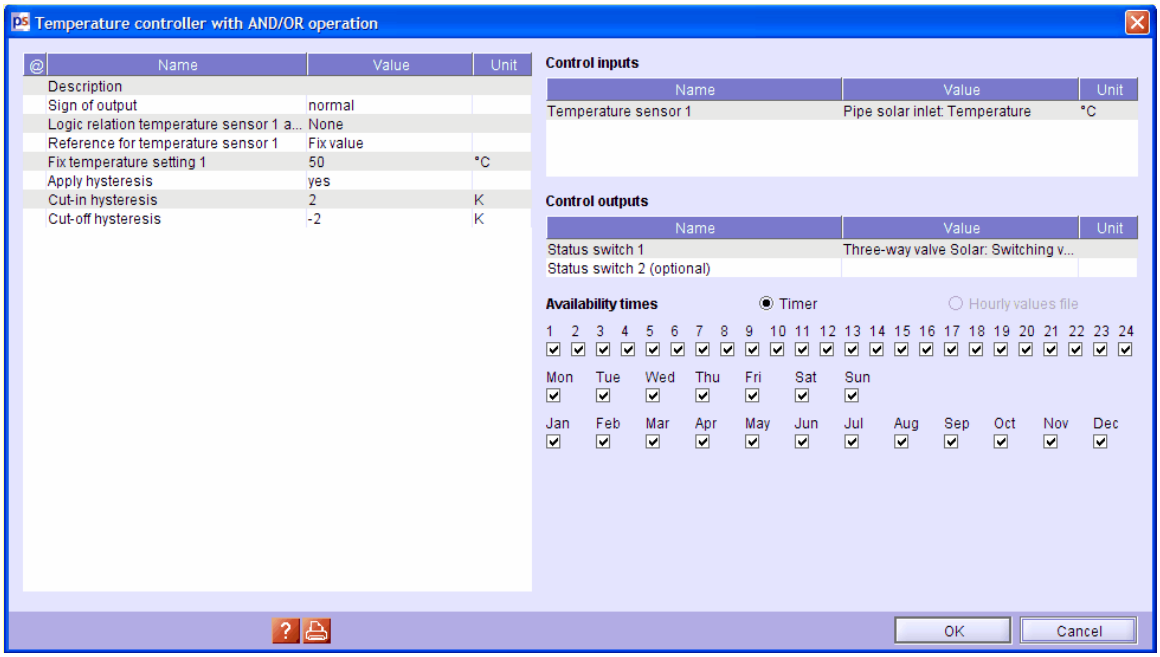


Figure 63: Controller input mask without logical connection once with ”Fixed value“ and once with ”Variable value“

With this setting the output located on the three-way valve and marked with X opens as soon as the pipe’s solar inlet temperature is higher than 50°C plus 2°.

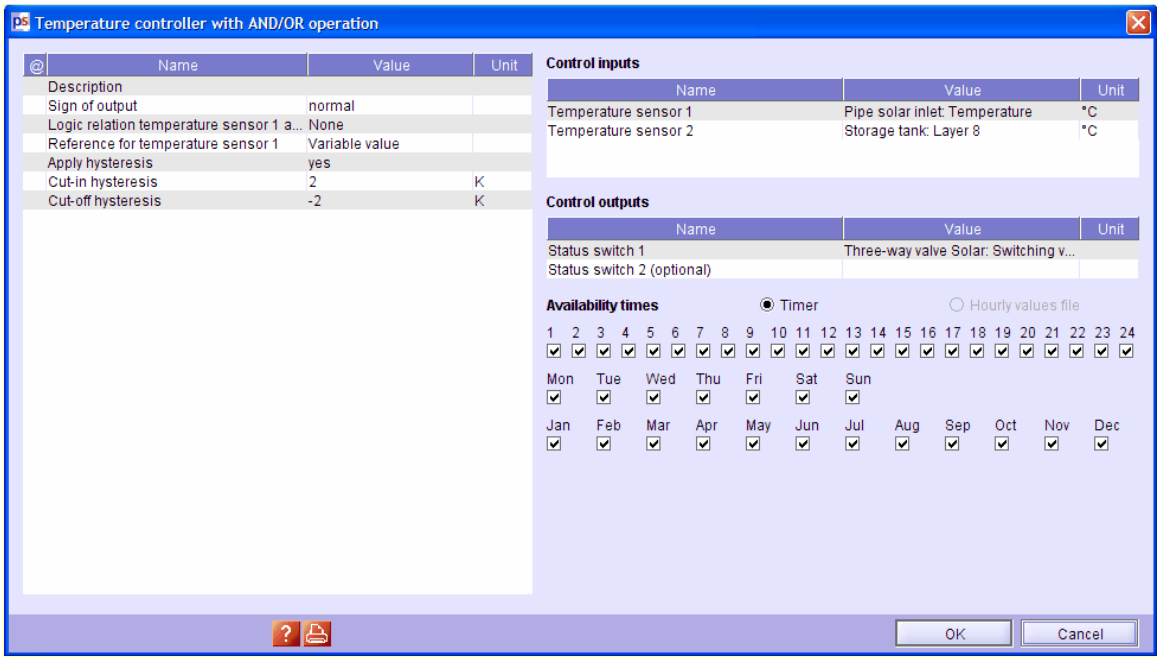


Figure 64: Controller input mask without logical connection once with ”Fixed value“ and once with ”Variable value“

With this setting the outflow located on the three-way valve and marked with X opens as soon as the pipe's solar inlet temperature is higher than the temperature on layer 8 plus 2°.

7.1.10.3 Controller input mask with logical connection once with "Fixed value" and once with "Variable value"

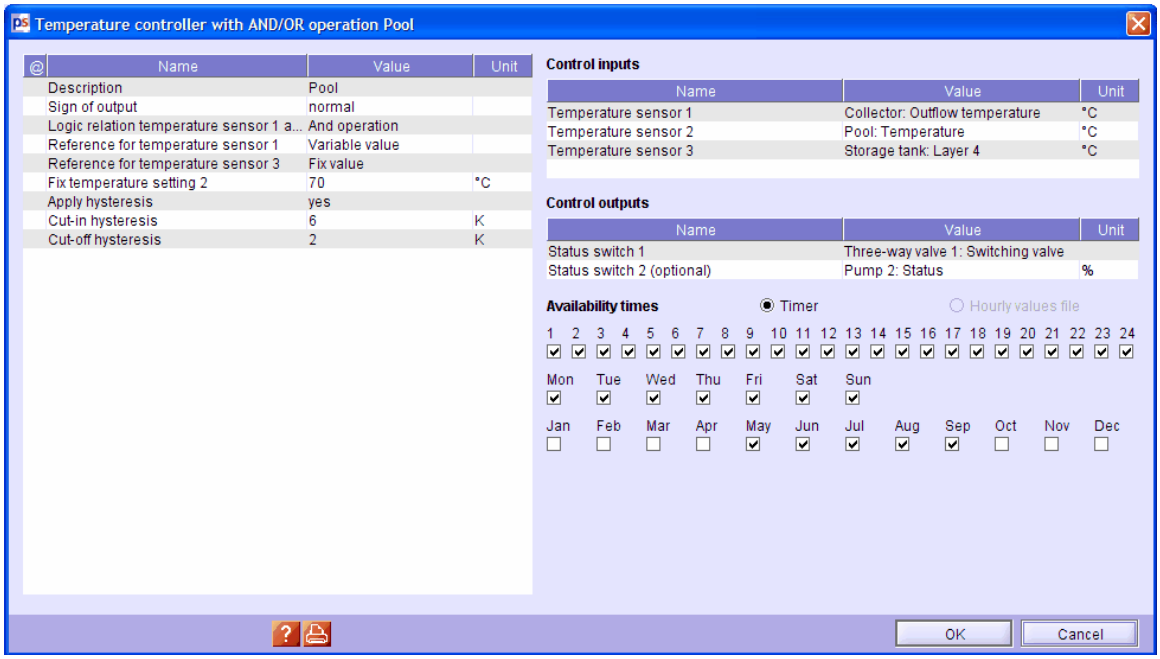


Figure 65: Controller input mask with logical connection "Fixed value" and "Variable value"

With this setting the swimming-pool pump is activated only if the temperature measured by Temperature sensor 1 (Collector: outflow temperature) is higher than the temperature measured by Temperature sensor 2 (Pool: temperature) AND the temperature measured by Temperature sensor 3 (Tank: Layer 4) is higher than the reference for Temperature sensor 3: Fixed value = 70°C. As the swimming-pool is only used from May through to September the timer will be set accordingly.

Input values

7.1.10.4 Temperature sensor 1 [℃]

The value refers to the point where the temperature should be measured. Enter a component from the list.

7.1.10.5 Temperature sensor 2 [℃] (Optional)

The value refers to the point where the reference temperature for temperature sensor 1 should be measured. Enter a component from the list.

7.1.10.6 Temperature sensor 3 [℃] (Optional)

In case of AND / OR operation an additional switching conditions may be defined. Analogous to Temperature sensor 1.

7.1.10.7 Temperature sensor 4 [°C] (Optional)

The value refers to the point where the reference temperature for temperature sensor 3 should be measured. Enter a component from the list.

Description of control-parameters

7.1.10.8 Description

The “description“ value enables the user to assign controllers any name of number. Polysun assigns a consecutive number as a standard feature as different controllers are added chronologically in the hydraulic system

7.1.10.9 Sign of the output

The term “Normal“ means that digital output signals are controlled as intended in the switching logics. (Example: if X1>Fixed value or if X1>X2 the output Status Switch 1 is positive). The term “Inverted“ means that the digital output signals are multiplied by -1. (Example: if X1>X2 the output Switch 1 is equal to zero). **In case of inverted selection hysteresis may not be used.**

7.1.10.10 Logical connection Temperature sensor 1 and 3

- None
  The output is activated based on the requirements existing amongst “Temperature sensor 1, Reference temperature, Temperature sensor 2 or Fixed temperature setting 1“.
- AND-Operation
  The requirements existing between “Temperature sensor 1, 2, Fixed temperature setting 1“, **AND** “Temperature sensor 3, 4, Fixed temperature setting 2“ must be met.
- OR-Operation
  The requirements existing between “Temperature sensor 1, 2, Fixed temperature setting 1“, **OR** “Temperature sensor 3, 4, Fixed temperature setting 2“ must be met.

7.1.10.11 Definition of temperature setting

- Fixed value
  If the temperature measured by Temperature sensor 1 or 3 drops below the specified Fixed temperature setting 1 or 2, the controller output switches to “on”.
- Variable value
  If the temperature measured by Temperature sensor 1 or 3 exceeds the temperature measured by Temperature sensor 2 or 4, the controller output switches to ”on“.

7.1.10.12 Use of hysteresis

If hysteresis is used the following applies

- Cut-in hysteresis [K]
  If the temperature measured by Temperature sensor 1 or 3 exceeds the

reference temperature by the specified temperature hysteresis, the controller output switches to ”on“.

- Cut-off hysteresis [K]
  If the temperature measured by Temperature sensor 1 or 3 drops below the reference value by the specified temperature hysteresis, the controller output switches to ”off“.

Output values

7.1.10.13 Status Switch 1

This digital output refers to the component to be controlled within the system. Select the relevant component from the list.

7.1.10.14 Status Switch 2 (Optional)

This digital output is activated just like the Status Switch 1 output. Select the relevant component from the list.

7.1.10.15 Overview of control-dependences

Outputs	Parameter	Tip	Inputs	Function	
Y1: Status Switch 1 Y1 = Y2 Y2: Status Switch 2	No operation Fixed value	*If hysteresis is applied alter cut-in and off temperatures*	X1: Temperature sensor 1	Y1=0 if X1 < Fixed temperature setting 1 [°C]	
				Y1=1 if X1 > Fixed temperature setting 1 [°C]	
				Y1=1 if X1 > Fixed temperature setting 1 [°C] + Cut-in-Hyst. Y1=0 if X1 < Fixed temperature setting 1 [°C] + Cut-off-Hyst.	
Y1: Status Switch 1 Y1 = Y2 Y2: Status Switch 2	No operation Variable value	*If hysteresis is applied alter cut-in and off temperatures*	X1: Temperature sensor 1 X2: Temperature sensor 2	Y1=0 if X1 < X2	
				Y1=1 if X1 > X2	
				Y1=1 if X1 > X2 + Cut-in temperature difference [K] Y1=0 if X1 < X2 + Cut-off temperature difference [K]	
Y1: Status Switch 1 Y1 = Y2 Y2: Status Switch 2	AND-Operation	*Both Temperature sensor 1 and 3 may be compared either with Fixed temperature settings 1 and 2 or with temperature sensors 2 and 4*	X1: Temperature sensor 1 X2: Temperature sensor 2 X3: Temperature sensor 3 X4: Temperature sensor 4	Y1=0 if	X1 < X2 or X1 < Fixed temperature setting 1 [°C] AND X3 < X4 or X3 < Fixed temperature setting 2 [°C]
				Y1=1 if	X1 > X2 or X1 > Fixed temperature setting 1 [°C] AND X3 > X4 or X3 > Fixed temperature setting 2 [°C]
				Hysteresis analogous to “No Operation“	
Y1: Status Switch 1 Y1 = Y2 Y2: Status Switch 2	OR-Operation	*Both Temperature sensor 1 and 3 may be compared either with Fixed temperature settings 1 and 2 or with temperature sensors 2 and 4*	X1: Temperature sensor 1 X2: Temperature sensor 2 X3: Temperature sensor 3 X4: Temperature sensor 4	Y1=0 if	X1 < X2 or X1 < Fixed temperature setting 1 [°C] OR X3 < X4 or X3 < Fixed temperature setting 2 [°C]

				Y1=1 if	X1 > X2 or X1 > Fixed temperature setting 1 [°C] OR X3 > X4 or X3 > Fixed temperature setting 2 [°C]
				Hysteresis analogous to “No Operation“	

7.1.11 Flow rate controller

The flow rate controller is a two-channel controller that regulates the status of up to two components and the flow rate of one pump based on a flow rate sensor. The controller is mainly used as a controller for the fresh-water station.

The controller has 1 (plus 2 optional) analogic inputs.

The controller has 1 (plus 2 optional) outputs, partially digital, partially analogic.

Switch cut-in or off are based on the comparison of two different flow rates. The comparison may be made with a constant value or in respect of a variable flow rate of any component. Additionally a scaling factor referring to a flow rate setting may be output as an analogic signal.

7.1.11.1 Block-diagram

The block diagram shows the employed measuring and controlling values

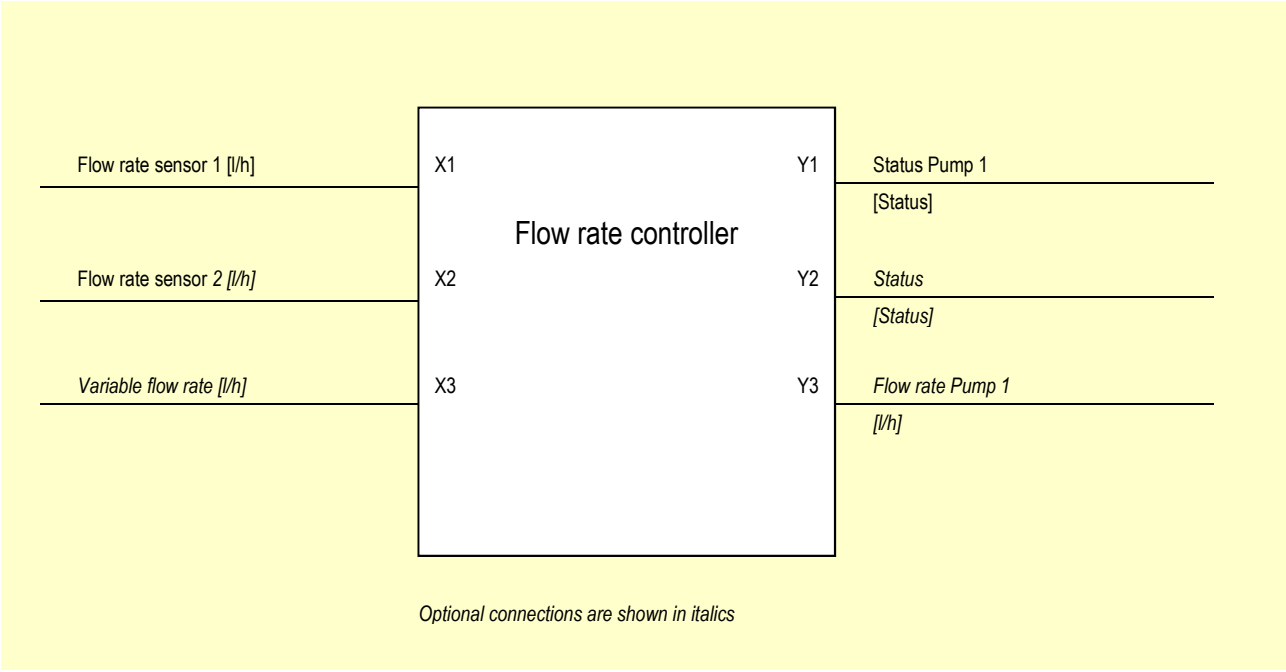


Figure 66: Block diagram: measuring and controlling values of flow rate controller

7.1.11.2 Controller input mask “Fixed value“

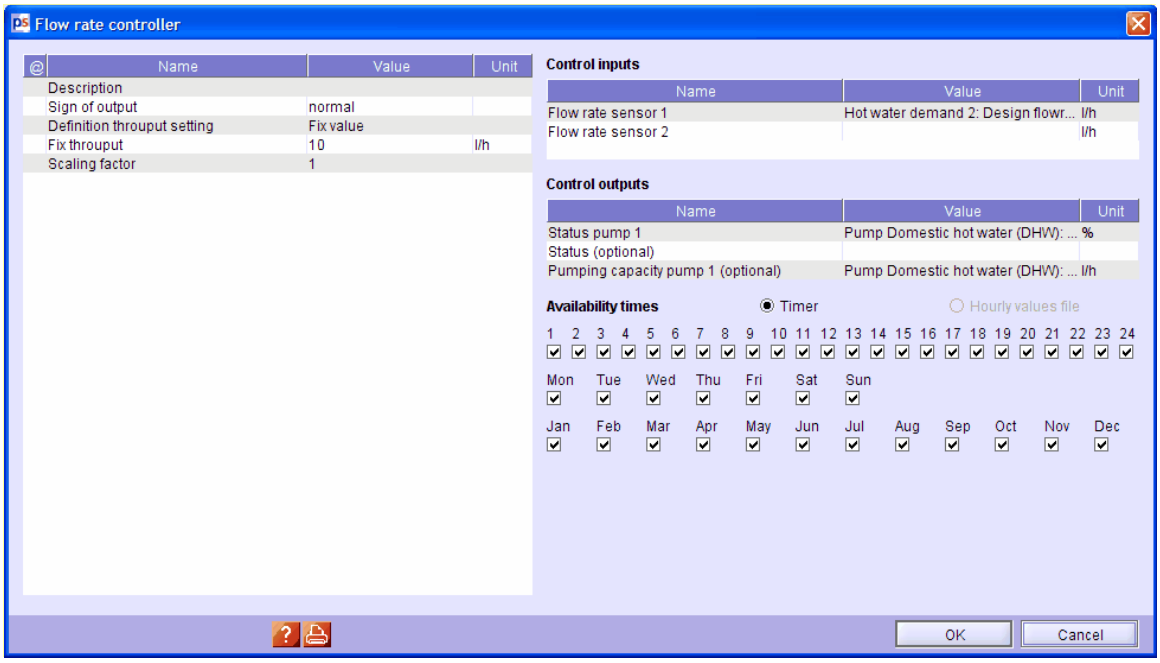


Figure 67: Flow rate controller input mask “Fixed value“

With this setting the hot water pump cuts in as soon as the flow rate of a tap is higher than 10 l/h. The tap flow rate will be referred to as the flow rate setting for the hot water pump.

7.1.11.3 Controller input mask “Variable value“

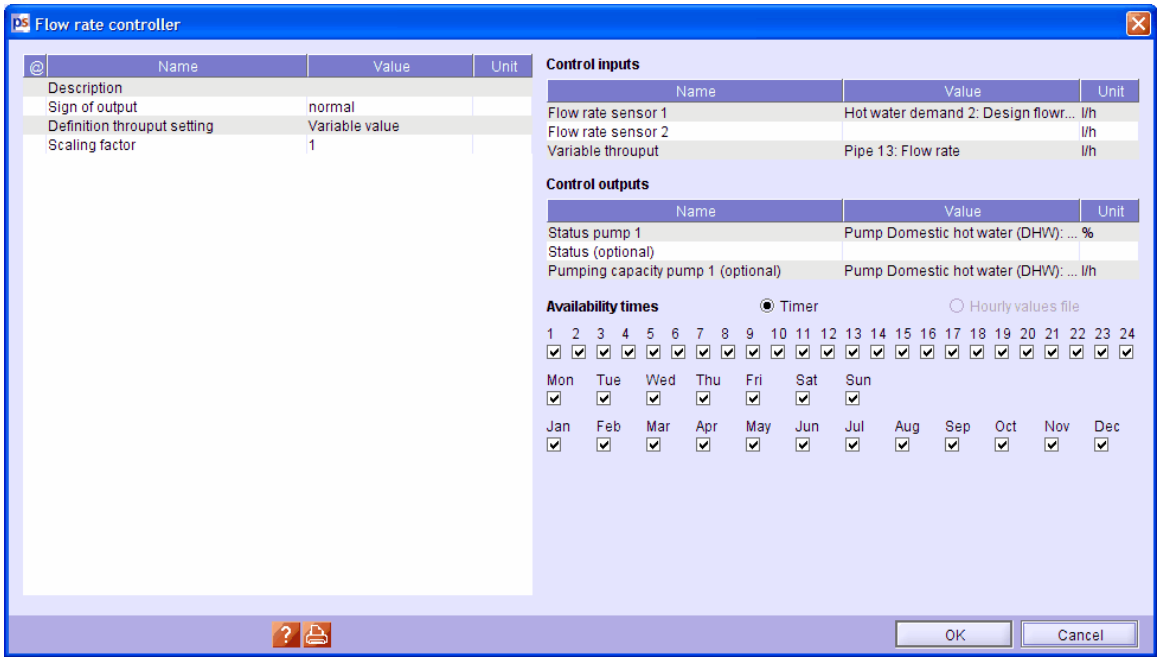


Figure 68: Flow rate controller input mask “Variable value“

With this setting the hot water pump cuts in as soon as the flow rate of the tap is higher

than the flow rate of pipe 13. The tap flow rate will be referred to as the flow rate setting for the hot water pump.

Input values

7.1.11.4 Flow rate sensor 1 [l/h]

The value refers to the point where the reference flow rate should be measured. Enter a component from the list. The value may be concurrently employed as output signal at the “Flow rate Pump 1“ output. In this context the value is multiplied by the ”Scaling factor“.

7.1.11.5 Flow rate sensor 2 [l/h]

An additional reference flow rate may be measured. Enter a component from the list. If 2 flow rate sensors are used their values are added. The added value may be concurrently employed as an output signal at the “Flow rate Pump 1“ output. In this context the value is multiplied by the ”Scaling factor“.

7.1.11.6 Variable flow rate [l/h] (Optional)

The value refers to the flow rate setting to be measured. The value serves as the reference value for flow rate sensor 1 or 1 + 2.

Description of control-parameters

7.1.11.7 Description

The “description“ value enables the user to assign controllers any name of number. Polysun assigns a consecutive number as a standard feature as different controllers are added chronologically in the hydraulic system

7.1.11.8 Sign of output

The term “Normal“ means that digital output signals are controlled as intended in the switching logics. (Example: if X1>Fixed value or if X1>X2 the output of pump 1 is positive). The term “Inverted“ means that the digital output signals are multiplied by -1. (Example: if X1>X2 the output Switch 1 is equal to zero).

7.1.11.9 Definition of flow rate setting

- Fixed value
  If the flow rate measured on the flow rate sensor exceeds the specified Fixed value the controller switches to “on”.
- Variable value
  If the flow rate measured on the flow rate sensor exceeds the specified Variable value the controller switches to “on”.

7.1.11.10 Scaling factor

The flow rate sensor value (X1+X2) is multiplied by the scaling factor and transferred via the “Flow rate Pump 1“ as output signal to the relevant pump.

Output values

7.1.11.11 Status Pump 1

This digital output refers to the component to be controlled within the system. Select the relevant component from the list. (For the fresh-water station select the pump).

7.1.11.12 Status (Optional)

This digital output is activated just like the output of Status Pump 1. Select if required a component to be controlled from the list.

7.1.11.13 Flow rate Pump 1 (Optional)

This option allows the pump to be speed-controlled. The flow rate setting is only active if the option "Flow rate setting" has been selected in the field "Flow rate controlled" for the pump to be controlled.

7.1.11.14 Overview of control-dependences

Outputs	Parameter	Tip	Inputs	Function
Y1: Status Pump 1 Y1 = Y2 Y2: Status	Fixed value	*Pump:enter in the field "Flow rate controlled" the value "Flow rate setting"*	X1: Flow rate sensor 1 X2: Flow rate sensor 2	Y1=0 if X1 + X2 < Fixed value [l/h] Y1=1 if X1 + X2 > Fixed value [l/h]
Y3: Flow rate Pump 1				Y3= (X1 + X2) * Scaling factor
Y1: Status Pump 1 Y1 = Y2 Y2: Status	Variable value	*Pump:enter in the field "Flow rate controlled" the value "Flow rate setting"*	X1: Flow rate sensor 1 X2: Flow rate sensor 2 X3: Variable flow rate setting	Y1=0 if X1 + X2 < X3 Y1=1 if X1 + X2 > X3
Y3: Flow rate Pump 1				Y3= (X1 + X2) * Scaling factor

7.1.12 Irradiance controller

The irradiance controller is a one-channel controller that regulates up to two components based on irradiance values. The controller is mainly used as a solar loop controller.

The controller has 1 (plus 1 optional) analogic inputs.

The controller has 1 (plus 1 optional) digital outputs.

7.1.12.1 Block diagram

The block diagram shows the employed measuring and controlling values

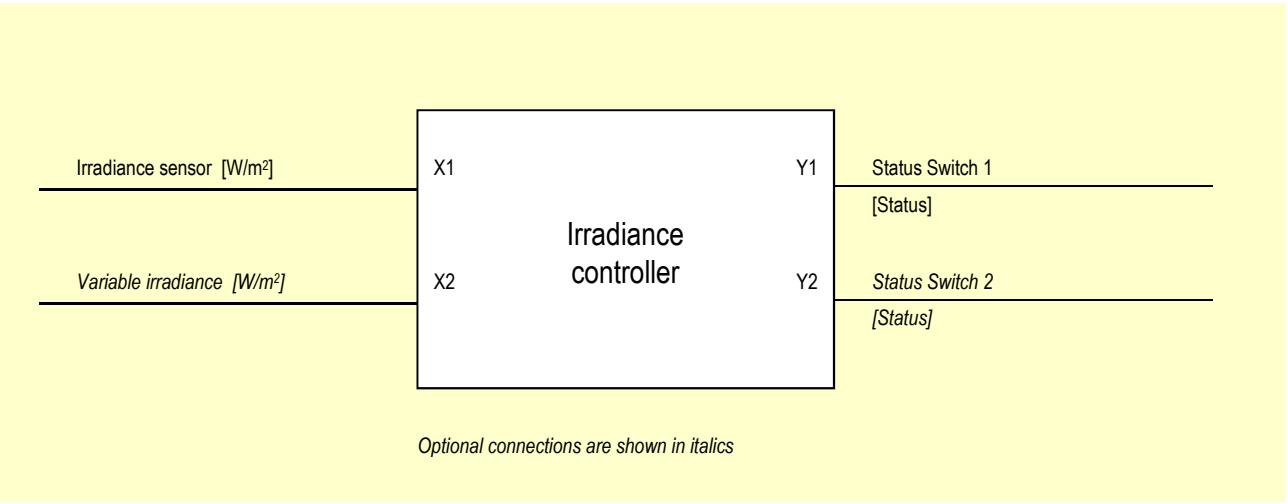


Figure 69: Block diagram: measuring and controlling values of irradiance controller

7.1.12.2 Controller input mask "Fixed value"

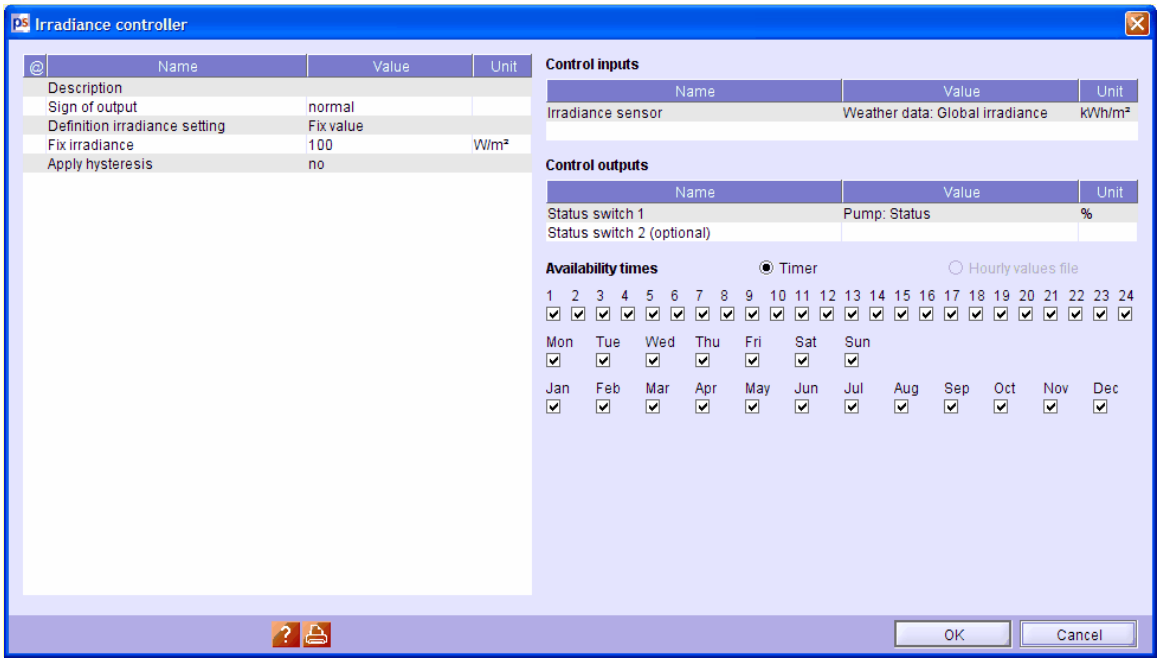


Figure 70: Irradiance controller input mask "Fixed value"

With this setting the pump cuts in as soon as the global irradiance is greater 100 W/m2.

7.1.12.3 Controller input mask “Variable value“

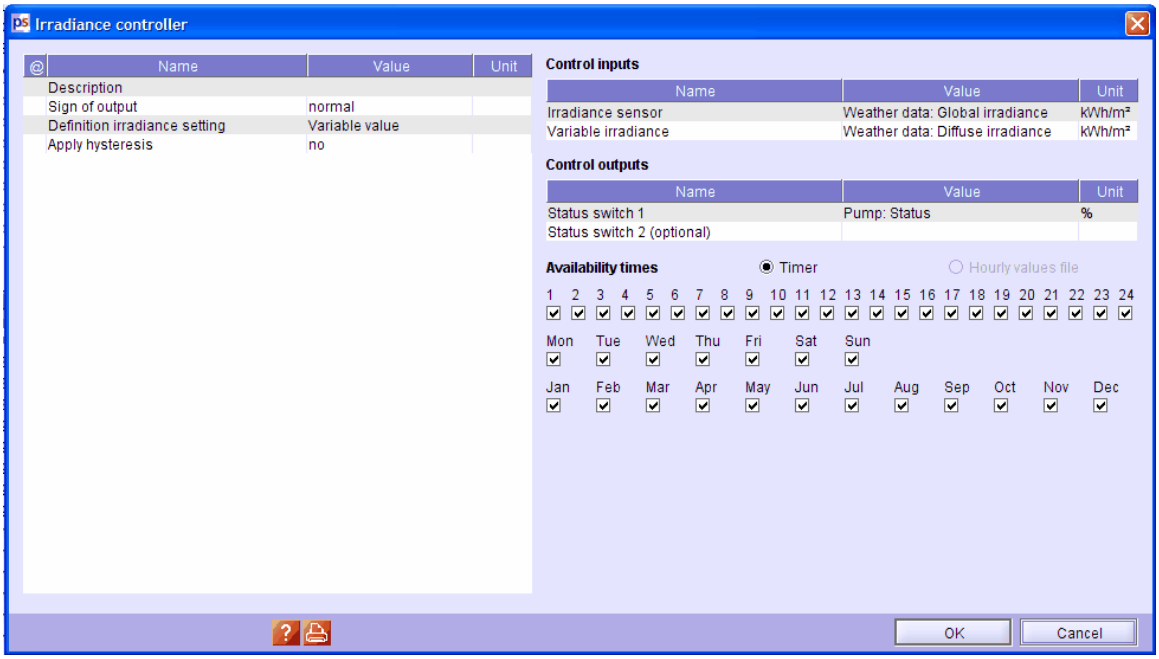


Figure 71: Irradiance controller input mask “Variable value“

With this setting the pump cuts is as soon as the global irradiance is greater than the diffuse irradiance.

Input values

7.1.12.4 Irradiance sensor [W/m^2]

The value refers to which irradiance should be measured. A distinction can be made between “Global irradiance”, “Diffuse irradiance“ and “Long wavelength irradiance”. Enter a component from the list.

7.1.12.5 Variable irradiance [W/m^2] (Optional)

The value refers to the diffuse irradiance setting to be measured. A distinction can be made between “Global irradiance”, “Diffuse irradiance“ and “Long wavelength irradiance”. Enter a component from the list.

Description of parameters

7.1.12.6 Description

The “description“ value enables the user to assign controllers any name of number. Polysun assigns a consecutive number as a standard feature as different controllers are added chronologically in the hydraulic system

7.1.12.7 Sign of output

The term “Normal“ means that digital output signals are controlled as intended in the switching logics. (Example: if X1>Fixed value or if X1>X2 the output of pump 1 is positive). The term “Inverted“ means that the digital output signals are multiplied by -1. (Example: if X1>X2 the output Switch 1 is equal to zero).

7.1.12.8 Definition of irradiance setting

- Fixed value
  If the irradiance measured by the irradiance sensor exceeds the specified fixed value the controller output switches to “on“.
- Variable value
  If the irradiance measured by the irradiance sensor exceeds the specified variable value the controller output switches to “on“.

7.1.12.9 Use of hysteresis

If the hysteresis is used the following applies

- Cut-in hysteresis [W/m^2]
  If the irradiance measured by the irradiance sensor exceeds the reference value by the specified hysteresis the controller output switches to ”on “.
- Cut-off hysteresis [W/m^2]
  If the irradiance measured by the irradiance sensor drops below the reference value by the specified hysteresis the controller output switches to ”off“.

Output Values

7.1.12.10 Status Switch 1

This digital output refers to the component to be controlled within the system. Select the relevant component from the list. For the switching valve the ”On“ status means that the output located on the switching valve and marked with “X“ is ”open”.

7.1.12.11 Status Switch 2 (Optional)

This digital output works just like output Status Switch 1. Select if required the component to be controlled from the list.

7.1.12.12 Overview of control-dependences

Outputs	Parameter	Tip	Inputs	Function
Y1: Status Switch 1 Y1 = Y2 Y2: Status	Fixed value	*If hysteresis is applied cut-in and cut-off criteria vary*	X1: Irradiance sensor	Y1=0 if X1 < Fixed value [W/m^2] Y1=1 if X1 > Fixed value [W/m^2]

Switch 2				Y1=1 if X1 > Fixed value + Cut-in hysteresis[K] Y1=0 if X1 Fixed value + Cut-off hysteresis [K]
Y1: Status Switch 1 Y1 = Y2 Y2: Status Switch 2	Variable value	*If hysteresis is applied cut-in and cut-off criteria vary*	X1: Irradiance sensor X2: Variable irradiance	Y1=0 if X1 < X2 [W/m^2] Y1=1 if X1 > X2 [W/m^2]
				Y1=1 if X1 > X2 + Cut-in hysteresis [K] Y1=0 if X1 < X2 + Cut-off hysteresis[K]

7.1.13 Programmable controller

The programmable controller enables operating states to be freely defined according to controller inputs as well as controller initial values to be set for each operating state. This makes the controller suitable for the most diverse applications. The control logic is defined by means of formulas that are comparable to the calculation formulas used in spreadsheets such as, e.g. Excel. For programmable controllers, the control logic is to be defined by the user, i.e., for standard applications such as, for example, a simple solar loop, the predefined controller ”Solar Loop Pump Controller“ will prove easier and faster to use; for special or more complex applications, the programmable controller provides the user with a much wider range of options to control the system component as desired.

7.1.13.1 Procedure

1. Create a **programmable controller** on the design area.
2. Define which **actuators** (elements) should be controlled.
   Limit yourself to the fewest possible elements having also a logical relationship to one another such as, for example, all the elements of a given loop. Using multiple controllers is easier than to use fewer but more complex ones. Establish a connection between controller outputs and the elements to be controlled.
3. Define which **sensors** are needed for the controller. Establish a connection between controller inputs and the measuring points of the different elements.
4. Consider which **operating states** may come into play for the combination of elements. Only a single state can be active during operation. Create an appropriate state for each operating state. For a solar loop, the operating states could be, for example, as follows: “Downtime” (too little radiation or full tank), “Charge tank”, “Cool down tank” (at night, if the tank gets too hot).
5. Use a formula to define the **conditions** required for a state to be activated.
6. Define for each state, which **initial values** should be assigned to the elements to be controlled.

7.1.13.2 Operators

Below we provide a description of the operators that can be used in the formulas.

Logical operations:

<	Returns the value 1 if the value to the left of the operator is **smaller than** the value to the right of the operator. Otherwise, the returned value is 0.
<=	Returns the value 1 if the value to the left of the operator is **smaller than or equal to** the value to the right of the operator. Otherwise, the returned value is 0.
>	Returns the value 1 if the value to the left of the operator is **larger than** the value to the right of the operator. Otherwise, the returned value is 0.
>=	Returns the value 1 if the value to the left of the operator is **larger than or equal** to the value to the right of the operator. Otherwise, the returned value is 0.
=	Returns the value 1 if the value to the left of the operator is **equal** to the value to the right of the operator. Otherwise, the returned value is 0.
<>	Returns the value 1 if the value to the left of the operator is not **equal** to the value to the right of the operator. Otherwise, the returned value is 0.
AND	Returns the value 1 if the value to the left **and** right of the operator is 1. Otherwise, the returned value is 0.
OR	Returns the value 1 if the value to the left **or** right of the operator is 1. Otherwise, the returned value is 0.
NOT	Returns the value 1 if the value to the right of the operator is 0. Otherwise, the returned value is 0.

Mathematical operations:

+	Returns a value which is the **sum** of the values to the left and right of the operator.
-	Returns a value which is the **difference** between the values to the left and right of the operator.
/	Returns a value which is the **quotient** of the values to the left and right of the operator.
*	Returns a value which is the **product** of the values to the left and right of the operator.
%	Returns a value which is the **integer quotient** of the values to the left and right of the operator.
^	Returns a value which is the **power** of the values to the left and right of the operator.

Expressions can be grouped and evaluated before others using brackets “(…)“. The formulas are evaluated in the following order:

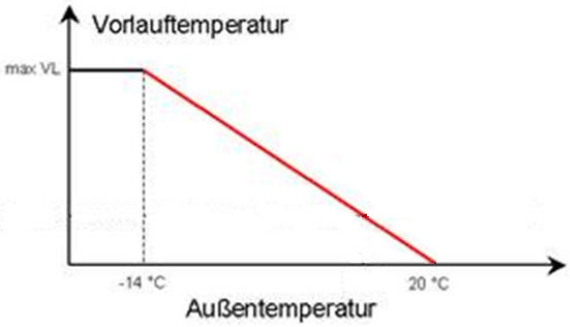
1. ^
2. * , /, %
3. +, -
4. <, , >, <=, >=, <>
5. =
6. NOT
7. AND
8. OR

7.1.13.3 Functions

Below we provide a description of the predefined functions that can be used in the formulas.

SQR	**Square** For example, SQR(4) returns the value 16.
SIN	**Sine** in radians For example, SIN(1.571) returns the value 1.
COS	**Cosine**, see also SIN
TAN	**Tangent**, see also SIN
SINH	**Hyperbolic sine**, see also SIN
COSH	**Hyperbolic cosine**, see also SIN
ATAN	**Arctangent**, see also SIN
COTAN	**Cotangent**, see also SIN
EXP	**Exponential function** For example, EXP(1) returns the value 2.718.
LN	**Natural logarithm** For example, LN(4) returns the value 1.386.
LOG	**Decadic logarithm** For example, LOG(10) returns the value 1.
SQRT	**Square root** For example, SQRT(4) returns the value 2.
ABS	**Absolute value** For example, ABS(-4) returns the value 4.
SIGN	**Sign**, returns -1 for negative, 1 for positive and 0 for 0 For example, SIGN (-4) returns the value -1.
TRUNC	**Integer part** For example, TRUNC(-3.7) returns the value -3.
CEIL	**Round up** to the next higher integer For example, CEIL(-3.7) returns the value -3.
FLOOR	**Round down** to the next lower integer For example, FLOOR(-3.7) returns the value -4.
RND	Integer **random number** The upper limit of the random number should be specified as an argument.
RANDOM	**Random number** with decimal places The lower limit of the random number should be specified as an argument.
MIN	**Minimum value** For example, MIN(2, 3) returns the value 2.
MAX	**Maximum value** For example, MAX(2, 3) returns the value 3.
IF	**If** (condition, return value for condition complied with, return value for condition non complied with) If the condition is complied with, the first return value will be returned as a result, otherwise the second. Operations too may be used as a return value; depending on the condition, only the appropriate return value will be evaluated. Several IF functions may be nested in one another. For example, IF(1>2, 3, 4) returns the value 4.
SUM	**Sum** of any number of arguments.

	For example, SUM(1, 2, 3) returns the value 6.
MATCHFLOW (T_i,Q,T_a,C_p,$\dot{V}_{min}$,$\dot{V}_{max}$)	**Regulation of a flow-rate** in l/to the desired temperature MATCHFLOW(T_i Inlet temperature in °C, for example to the collector, Q Power in W, for example power of the collector, T_a Outlet temperature in °C, for example the desired target temperature, C_p Heat capacity in J/(l*K), for example, the heat capacity of the fluid, $\dot{V}_{min}$ V̇min. flow-rate in l/h, for example the lower limit of the pump, $\dot{V}_{max}$ max. flow-rate in l/h, for example the upper limit of the pump) $$\dot{V} = \frac{\dot{Q}}{C_p * (T_a - T_i)} * 3600$$
MATCHPOWER (T_i, $\dot{V}$, T_a, C_p, $\dot{Q}_{min}$, $\dot{Q}_{max}$)	**Regulation of a flow-rate** in W to the desired temperature MATCHPOWER(T_i Inlet temperature in °C, for example to the boiler $\dot{V}$ Flow-rate in l/h, for example, flow-rate of the boiler pump, T_a Outlet temperature in °C, for example the desired target temperature, C_p Heat capacity in J/(l*K), for example, the heat capacity of the fluid, $\dot{Q}_{min}$ min. power in W, for example the lower limit of the boiler pump, $\dot{Q}_{max}$ max. power in W, for example, the upper limit of the boiler pump) $$\dot{Q} = (T_a - T_i) * C_p * \dot{V} / 3600$$ If Qmin / Qmax 0 the values will not be taken into account; otherwise, the result Q will be restricted to these minimum/maximum values before being returned.
MATCHRATE (T_u, T_l, T_o)	**Regulation of a mixing ratio** to the desired temperature MATCHRATE(T_u Upper level temperature in °C, for example hot water inlet to mixing valve, T_l Lower level temperature in °C, for example cold water inlet to mixing valve, T_o Outlet temperature in °C, for example the desired target temperature) $$p = \frac{T_o - T_l}{T_u - T_l}$$
MEANVALUE (a, b)	**Arithmetic mean value of two values** MEANVALUE (a value 1, for example a temperature value from the latest time step Value 2, for example a temperature value from the current time step) $$m = \frac{a + b}{2}$$
HEATINGCURVE(T_{soll}, T_{a_norm}, a, T_a)	**Regulation of temperature based on the heating curve (function HEATINGCURVE)**

	 The function adopts 4 parameters: T_{soll}: nominal inlet temperature heating elements (= max VL in the chart) [°C] T_{a_norm}: design outdoor temperature (for the T_{soll} gilt (= -14°C in the chart)[°C] a: heating curve gradient T_a: current outdoor temperature [°C] The point (= 20°C in the chart) where the curve meets the x-axis is determined from the remaining parameters.

7.1.13.4 Variables

In the formulas, different variables are available to access controller inputs or outputs or other statuses of the simulation.

I1 I2 … I16	Current value of a **controller input** Value of the controller input in the current time step of the simulation. Only variables that are linked to sensors are allowed for use.
PI1 PI2 … PI16	Latest value of a **controller input** Value of the controller input from the latest time step of the simulation. Only variables that are linked to sensors are allowed for use.
O1 O2 … O16	Current value of a **controller output** Value of the controller output in the current time step of the simulation. Only variables that are linked to actuators are allowed for use.
PO1 PO2 … PO16	Latest value of a **controller output** Value of the controller output from the latest time step of the simulation. Only variables that are linked to actuators are allowed for use.
H1 H2 … H8	Current value of an **auxiliary variable** (constant, formula or time delay) Value of the auxiliary variable in the current time step of the simulation. Only previously defined variables are allowed for use.
PH1 PH2 … PH8	Latest value of an **auxiliary variable** (constant, formula or time delay) Value of the auxiliary variable from the latest time step of the simulation. Only previously defined variables are allowed for use.
S	Number of the active **status** (operating status) in the current time step of the simulation. The variable may include values ranging from 1 to the number of

	defined states (max. 16).
PS	Number of the active **status** (operating status) from the latest time step of the simulation. The variable may include values ranging from 1 to the number of defined statuses (max. 16).
TS	Current **time step** in seconds since the start of the simulation (January 1st 00:00)
PTS	Last **time step** in seconds since the start of the simulation (January 1st 00:00)
TC	Signal of the **time switch** from this controller. Returns the value 1 if the time switch is on, 0 if the time switch is off.
PI	Constant π

All numbers included in the formulas should use the "point" as a decimal separator (regardless of the "Language and Region" setting in Polysun). The symbol "E" may be used as an exponent, for example 1234.6 or 1.2346E3

Controller inputs may be used for the following variables. For the variables from I1 to I16 or from PI1 to PI16, the value is returned in the following basic unit (regardless of the "Units" setting in Polysun):

Temperature	°C
Area	m^2
Power	W
Specific power	W/m^2
Thermal conductivity	W/K
Heat capacity	J/(l*K)
Flow-rate	l/h

Controller outputs may be used for the following variables. For the variables from O1 to O16 or from PO1 to PO16, the value is returned in the following basic unit (regardless of the "Units" setting in Polysun):

State	Without unit, on/off signal, value 0 or 1
Percentage	Without unit, analogue control signal, value from 0 to 1
Leistung	W
Flow-rate	l/h

7.1.13.5 State

A "state" is a possible operating state of the group of elements to be controlled. For a heat pump equipped with a switching valve for tank charging, the operating states could be the following: "Charge tank for space heating", "Charge tank for domestic hot water".
For each state, the user can use a formula to define when this is active. Only one state can be active at a time. As soon as a state is found for which the formula returns the value 1, the number of this state is written into the S variable and the following formulas of the remaining states are no longer processed. If no active state is found, the state from the latest time step is retained.

7.1.13.6 Auxiliary variables

Auxiliary variables can be used in three different ways.

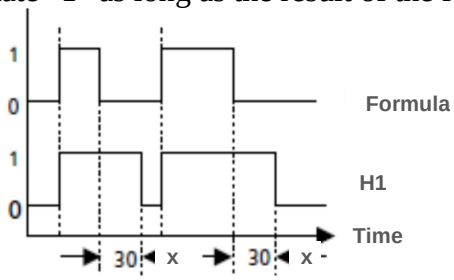
Constant

The auxiliary variable may be used as a constant with a unit. The entered value is converted to the basic unit and may be used in the formulas for states or outputs through the variables from H1 to H16 or from PH1 to PH16.
So, for example, a cut-in temperature may be comfortably entered in the unit system (°C or F) that can be set in the Polysun settings without the need for the value to be searched for and adapted in the formulas.

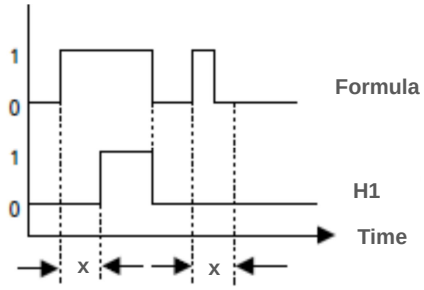
Formula
Entering a formula, the user can calculate an intermediate result that may be used in the formulas for states or outputs through the variables from H1 to H16 or from PH1 to PH16.
So, for example, you may calculate an intermediate result that can be re-used in several formulas.

Time-delay
With a time-delay, signals may be delayed or extended. There are four different types of delay that are listed below. With a formula, the user can define when the delay should start (result of the formula = 1). With the variables from H1 to H16 or from PH1 to PH16, the user can check in the formulas for states or outputs whether the time function has run out (1 = running, 0 = run out).
So, for example, a pump can be switched on with a delay after the switch-on condition is fulfilled in order to avoid it being turned on and off too frequently.
As the length of time steps is variable, the entered time delays may be not exactly complied with. Time functions may only start or run out when a time step is running.

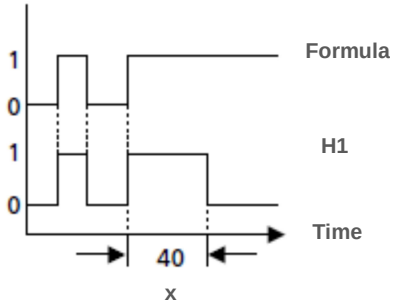
- SA Start of a time as a cut-off delay.
  If the result of the formula changes to “0“, the entered time runs out. If the result of the formula changes again to “1“, the time is restored to the initial value. A query returns the state “1“ as long as the result of the formula = ”1“ or the time is running.



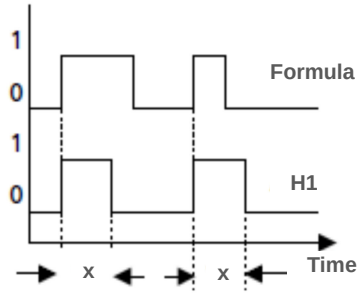
- SE Start of a time as a cut-in delay.
  The time starts when the edge of the result of the formula is rising. If the result of the formula = “0“ the time is set to ”0“. Queries return “1“ only when the time has run out and the result of the formula is still pending.



- SI Start of a time as an impulse. The time starts when the edge of the result of the formula is rising. Queries return ”1“ as long as the time is running. If the result of the formula = ”0“ the time is likewise set to ”0“ and the query returns ”0“.



- SV Start of a time as an extended impulse.
  The time starts when the edge of the result of the formula is rising. A result of the formula = “0“ does not affect the time. Queries return “1“ as long as the time has not yet run out.



7.1.13.7 Processing sequence

In the Polysun simulation, a year is calculated from January 1st,00:00 to December 31st, 24:00, possibly with an advance that can be selected for the variant. The time steps for the simulation have a variable length ranging from one second to max. 4 minutes (during the day) or 12 minutes (at night). For each time step, controllers are processed first, then all elements.

In each time step of the simulation, variables or formulas for the controller are processed in the following order:

1. Evaluation of time step and time-switch and allocation to variables TS and TC.
2. Reading of controller inputs and allocation to variables from I1 to I16 or from PI1 to PI16.
3. Processing of auxiliary variables, starting with the first auxiliary variables and allocation to variables from H1 to H16 or from PH1 to PH16.
4. Evaluation of the conditions of the state, starting with the first state. The evaluation is interrupted at the first active state. The number of this state is then allocated to the S variables or the previous number is allocated to the PS variable.
5. Processing of the controller outputs of the active state, starting with the first controller output. Allocation to the variables from O1 to O16 or from PO1 to PO16.

This processing sequence reveals that only variables of the current values which were already processed in the sequence may be read. So, for example, in the formulas for auxiliary variable 3, variables H1 and H2 can be read, not variable H3, H4, etc.; likewise in the formulas for the state, only PS variables can be read, but not S variables and, for example, in the formula for controller output 2 the variable O1 can be read, but not variables O2, O3 and so on.

7.1.13.8 Comments

Within formulas you will be able to insert comments at any point by positioning them between two hash symbols („#“),
e.g.: I1 > I2 + 6 #Start-up hysteresis# AND I2 < 70 #Maximum tank temperature#

8 Economic viability

The economic viability calculation is started by pressing the CTRL + SHIFT + A buttons or following the Results → Economic viability path. All relevant entries may be adjusted in the project overview.
The economic viability calculation in the economic viability dialogue box requires as a standard values to be imported from the project. However corrections and adjustments may be also made in the Results window (upper section of the dialogue box). The button "Transfer data" allows the edited entries to be re-imported into the project; should the values have been edited and the window be closed the data will be lost.

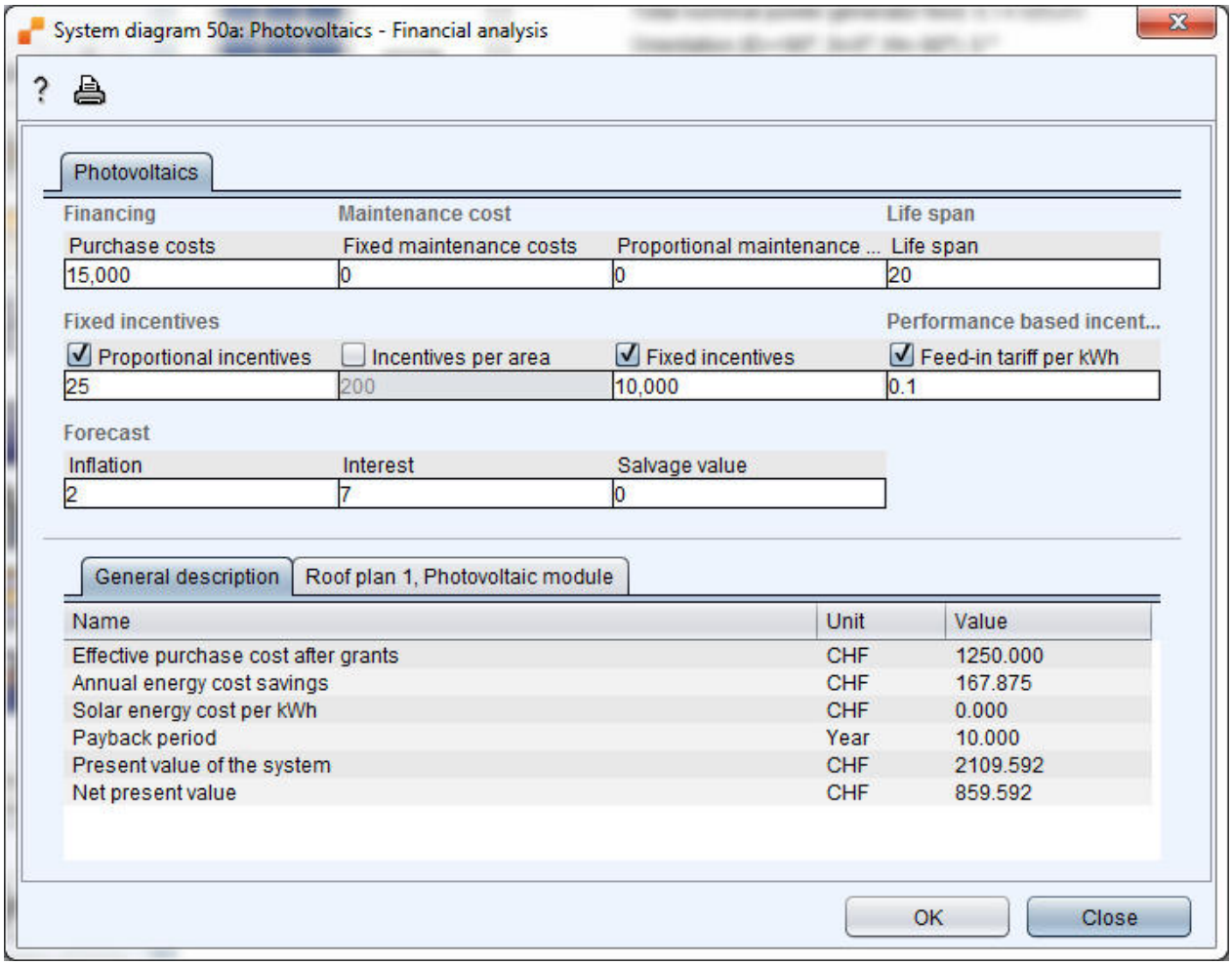


Figure 72: Economic viability dialogue box

The fuel catalogue allows the user to generate new entries that will automatically appear in the Economic viability window under "Energy prices". This allows users to save fuel prices individually in the catalogues.

8.1 Calculation basis

Polysun enables users to include in the economic viability analysis a series of economic influencing factors.

- System purchasing costs
- Maintenance costs
- Lifespan
- Fixed and variable subsidies
- Inflation, interest, energy prices and increase in energy prices
- Scrap value

Input parameters:

Discounted purchasing costs	Discounted purchasing costs after incentives	A
Collector area	Gross collector area in m²	A_{col}
Generated/saved energy	For thermal systems: Q_{sol} For PV systems: Q_{inv}	B_E
Fed-in energy	Fed-in energy in kWh	E_a
Annual maintenance costs:	Fixed annual amount: Annual percentage of purchasing costs C_{CI}:	C_{FV} C_{FI}
Cost of a complete solar system (inclusive of installation):	Purchasing costs; investment costs	C_{CI}
Financial incentives:	Fixed amount on purchasing costs: Fixed amount per m^2 of gross collector area: Percentage on purchasing costs: Feed-in tariff per kWh: Heat production tariff per kWh:	C_{CS} C_{CF} f_{CS} b_{FI} b_{GT}
Energy cost increase:	Percentage cost increase per year:	E
Inflation:	Percentage inflation rate:	I
Lifespan:	In years	n
Fuel price:	Price per kWh	P_F
Interest:	Percentage return on investment:	r
Scrap value:	Value of system at end of lifespan:	S
Fuel savings	Annual fuel savings in kWh	S_a

Results

Actual system purchasing costs after incentives	C_0
Annual fuel savings in litres of oil, m^3 Gas, kg firewood or pellets, etc (like in the ”Component results“ view)	B_{FS}
Annual revenue from heat production tariff	B_{GT}
Solar energy costs per kWh	P_{SE}
Amortisation period	T_{dp}
Current value of system (interest, inflation and energy price increase balanced)	P_0
Net cash value of system	NPV

Formulas:

Purchasing costs after financial incentives: $C_0 = C_{CI} * (1 - f_{CS}) - C_{CS} - C_{CF} * A_{col}$

Annual profit through fuel savings: $B_{FS} = S_a * P_F$ (for thermal systems only)

$B_{FS} = S_a * b_{FI}$ (for PV systems only)

Annual revenue from heat production tariff $B_{GT} = E_a * b_{GT}$ (for thermal systems only)

In case of feed-in tariffs (b_{FI}) or heat production tariffs (b_{GT}), the energy price increase (E) is equal to 0.

Cash value: [d]: $d = \frac{r-I}{1+I}$

Annual repair and maintenance costs [C]: $C = C_{FV} + C_{FI} + C_{CI}$

Current value of system (interest, inflation and energy price increase balanced) [P_0]:

$$P_0 = \frac{B_{GT}}{0-d} * \left[\left(\frac{1+0}{1+d}\right)^n - 1\right] + \frac{B_{FS}}{E-d} * \left[\left(\frac{1+E}{1+d}\right)^n - 1\right] - C * \left[\frac{(1+d)^n - 1}{d * (1+d)^n}\right] + \frac{S}{(1+d)^n}$$

Net cash value [NPV]:

$$NPV = \frac{B_{GT}}{0-d} * \left[\left(\frac{1+0}{1+d}\right)^n - 1\right] + \frac{B_{FS}}{E-d} * \left[\left(\frac{1+E}{1+d}\right)^n - 1\right] - C * \left[\frac{(1+d)^n - 1}{d * (1+d)^n}\right] - C_0 + \frac{S}{(1+d)^n}$$

The system's net cash value results from the future discounted cash flows (annual fuel savings through solar system, annual feed-in tariff), the annual discounted costs and the system's scrap value. This formula yields the system's cash value allowing for its lifespan and the future trends of prices and interest rates (inflation, interest and energy prices).

One must note that a high feed-in tariff, high annual fuel savings and a long lifespan may result in a high net cash value.

The cash value of a system should not be confused with its yield. The cash value should essentially serve as a basis for the decision to invest in a system as opposed to others, considering the various influencing factors that may affect the system over its lifespan.

Amortisation period [T_{dp}]:

The amortisation period is calculated using the formula for the net cash value. Here, the amortisation period corresponds to the period (n) with an NPV equal to zero. As the conversion of the formula does not yield an explicit solution, Polysun uses values ranging from 1 to 100. The first n period yielding a positive NPV is then displayed as the amortisation period.

Solar energy price for thermal systems [P_{SE}]:

$$A = C_0 * \left[\frac{d * (1+d)^n}{(1+d)^n - 1}\right]$$

$$P_{SE} = \frac{A + C}{B_E} - b_{GT}$$

Solar energy price for PV systems [P_{SE}]:

$$A = C_0 * \left[\frac{d * (1+d)^n}{(1+d)^n - 1}\right]$$

$$P_{SE} = \frac{A + C}{B_E} - b_{FI}$$

9 Tips and tricks to work with Designer

9.1 Adapting a template

The easiest way to create a user-defined system scheme is to adapt a similar, existing template. Here, an advantage is that the controllers for the unchanged components are already configured. Below are some tips:

- **Replicability:** in order to always be able to revert to a functioning variant, always copy the variant and save the project after each process step. In addition, the simulation should be started and results should be checked so that any errors can be detected as early as possible.

- **Tank replacement:** Should changes be made to connections or internal components of the tank, a new tank is to be entered in the scheme. Following this, controllers should be checked and the relevant sensors be set on the new tank. If any component is removed from the scheme, the associated references in the controllers will be removed too – therefore, it is advisable to initially only remove pipe connections to the old tank and to remove the old tank from the scheme only after installing the new one and adjusting the controllers. This way, before the old tank is removed, you will still be able to identify in the controllers which in and outputs should be adjusted.

9.2 Designing a new system scheme

If you do not wish to adapt an existing template, you may perform the following steps to design a completely new scheme altogether. Here too, we recommend the variants are regularly copied as a backup. If the scheme to design is a complex one, it may make sense to first design a simplified version of it and gradually add more complex features on a functioning base.

1. Place all required components on the design area.

2. Connect components.

3. Start simulation. If the simulation is running, Polysun can calculate the designed scheme. Due to the missing controllers, the results are not yet significant (i.e. the calculation can be interrupted, it is enough to check whether or not the simulation is starting). If the simulation does not start, an error message referring to the cause will be displayed. For further information see the Trouble shooting section.

4. Now, controllers can be added step by step. After adding each controller, it is always advisable to check whether the scheme is still functioning.

5. Check the results, e.g. with the aid of component results.

9.3 Controller settings

- Where possible, use variable values, e.g. in the heat generator controller set the “Reference for temperature sensors 1“ field on the left-hand side to “Variable value“

and on the right-hand side, in the ”Controller inputs” field, select the hot water demand temperature setting for ”Temperature sensor 1“. This allows hot water tapping temperature to be modified without the need for controllers to be adapted.

- Should the status of a mixing valve or the flow-rate of a pump be set through a controller, components must be set accordingly. Otherwise, the value pre-set in the components will be used.
  Three-way valve: set “Branching model” option “Set value“
  Pump: set “Flow-rate controlled“ to “Flow-rate setting“

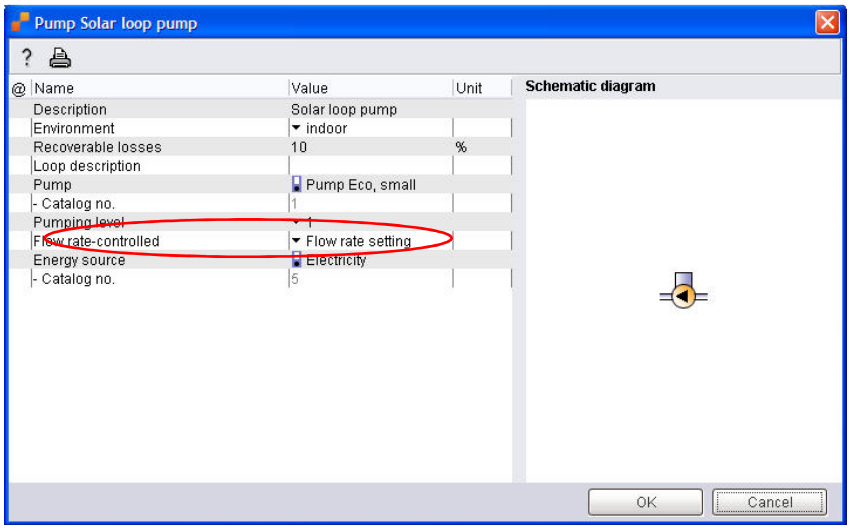


Figure 73: pump settings

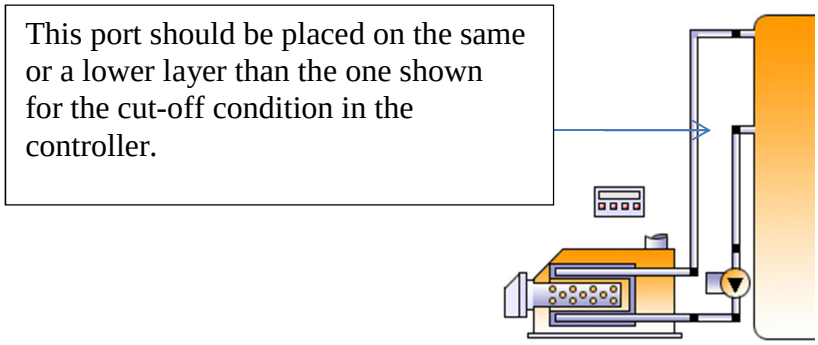
- If the parameters available for a controller are too few, an OR-operation of both controllers may be performed by means of two pumps arranged in parallel within the circuit, each with a controller.

- The indication of tank layers in the controllers is important and should be in line with ports and coil heat exchangers. At the same time, care should be taken to ensure that ports and coils are regularly distributed on the displayed tank image; however, for the simulation, the relevant heights are those listed in the tank catalogue. In particular, tanks designed for water-pump systems have different port heights. It will be helpful to drag your mouse over the controller to see what height in the tank the sensors are pointing to.

Heat generator controller
If a heat generator is connected to the tank, the value for the cut-off condition in the “Heat generator controller“ field must refer to the same or a higher layer than the one the return port is placed on.

Example of an incorrect controller setting:
The return port is at 60%. The boiler cuts in when layer 8 (58.3-66.7%) in the tank drops below 50°C. The cut-off condition is that temperature in layer 6 (41.7 – 50%) is 60°C. This is never reached as the boiler return lies at 60% (above layer 6) and therefore layer 6 cannot be effectively warmed up. Heating occurs on layer 8, where the return port is installed, and above.

The heating continues until the maximum tank temperature configured in the controller is reached as the cut-off condition does not become effective.
The correct setting for the cut-off condition is on layer 8 or higher.



9.4 Trouble-shooting

System scheme is not running
If the simulation cannot start, an error message referring to the cause is displayed. Possible issues are:

- Open pipe connections (all connections, tank connections included, must be connected with pipes)
- Undetermined flow direction in a circuit, a pump or a three-way valve are missing. A circuit may also be over-determined, e.g. if two pumps are installed in series within the same circuit. The following components can determine flow direction:
    - Pump
    - Boiler/heat pump with internal pump
    - Cold + hot water connection
    - Three-way valve
- If an error message is displayed saying the circuit is too complex (Error n. 5070/21), the three-way valve should possibly be replaced with a T-piece.

Simulation is running slow
A long simulation time is suggestive of a failure during the simulation. If significant temperature differences are observed between two distinct calculation steps, Polysun reduces the duration of the time step and calculates again, which causes simulation time to increase. Generally, complex and/or large systems have longer simulation times.
In such case, an effective way to find errors is to switch-off controllers consecutively and observe in which case the simulation runs faster. To do so, disable all months in the availability times of the respective controller.

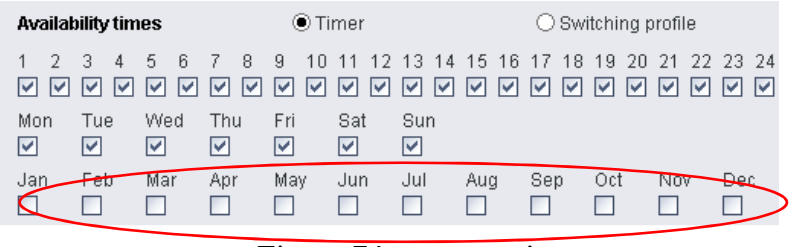

Availability times
Timer
Switching profile
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Mon Tue Wed Thu Fri Sat Sun
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

Figure 74: pump settings

Possible causes include, for example, a controller that keeps switching on and off or an over-definition of flow direction in a circuit, for example, due to unnecessary three-way valves.

Avoid having two different flow directions in a pipe; particularly, in the case of pipes connected to a tank this may result in incorrect results. A better option is to use an additional port (port heights may be altered through the tank catalogue, so, for example, also ports marked on the cap may be used as a connection further down).

Badly placed tank-ports or referencing a layer lying too high or too low in a controller may also be an issue. Temperature distribution in the tank may be suggestive of this problem. The individual tank layers can be seen in the component results, tabular and graphical evaluation.
Energy demand not met
If at the end of the simulation this message is displayed, this may be due to a number of reasons including but not limited to:

- The tank is too small
- The tank cannot reach the required temperature
    - Availability times for auxiliary heating (boiler/heat pump/electric resistance heaters) are set too short in the controller.
    - The boiler is too small/heat pumps and possibly the borehole are too small
- In the controller, use “Variable value“ instead of fixed values, e.g. to refer to the hot water temperature setting.
- The mixing valve (for hot water and/or heating circuit) is set to a temperature that is too low. If required, configure a temperature shift to offset pipe losses.

Additional causes if the hot water demand is not met:

- For tank-in-tank systems: surface or volume of the inner tank are too small.
- The piping between the heat source and the tap is too long and this results in significant heat loss (circulation required)
- For fresh-water stations: pumps or plate heat-exchangers are too small.

Additional causes if the heating energy demand is not met (the desired temperature was not always reached in the building during the heating period):

- The night temperature set for the building is too low as compared to daytime temperature (the warm-up phase is too long)
- The number of convectors is too small (in the convector settings, set ”Number of modules automatic“ to ”Yes”)

Possible causes if the cooling demand is not met (= in the cooling period the building was above the desired temperature)

- The chiller is too small
- The number of fan-coils is too small (in the fan coil settings, set ”Number of modules automatic“ to ”Yes”)
- In the building settings, “Shading” and “Natural ventilation” were not set.

Heat pump low-pressure/high-pressure failure
Air-water heat pumps have two self-protection temperature limits, brine/water-water heat pumps have three. If the temperature drops below the low-pressure failure temperature (brine/water-water heat pumps only) or exceeds the high-pressure failure temperature (2^{nd} type), the heat pump cuts off. As a rule, the connected pumps are regulated by the heat generator controller, for which reason they keep running in case of failure. If the failure occurs too frequently (see component results), this could be due to the fact that hot water demand may no longer be met. Possible causes for the failure:

- Low-pressure failure: the heat source or the borehole are too small
- The heat pump is too large
- Flow rate on source or consumer side is too large
- The temperature in the tank is too high or the position of ports does not fit controller settings
- The configuration of safety temperatures in the heat pump settings (double click on the heat pump) is incorrect

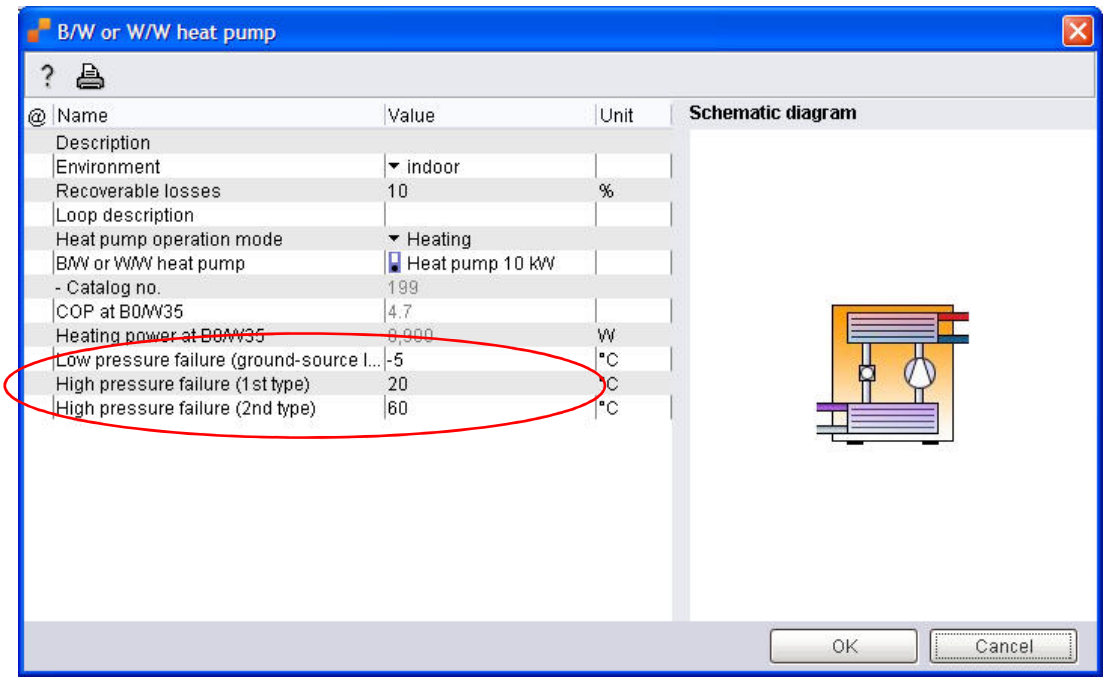


Figure 75: Brine/water-water heat pump settings

Limitations

- **Non-return check valve**: in Polysun, there are no non-return check valves. Indeed, non-return check valves are used for maintenance purposes, however, they are not relevant for the simulation. In addition, non-return check valves are installed to prevent an unwanted flow against the direction of the pump when the latter is switched off. In Polysun, pumps are ideal, i.e. when the pump is off nothing flows in or against the direction of the pump. Flow directions in the pipes are, thus, in any case clearly defined through pumps and three-way valves, which makes non-return check valves irrelevant for the simulation.

- **Multipliers**: as a general rule, only a couple of inflow/outflow multipliers should be used in a scheme.

- **Parallel tanks**: the connection of parallel tanks is not advisable. The use of a single, large tank provides in most cases good approximation and a more stable simulation. Tanks connected in series are also possible.

- **Flow rate producer / three-way valve**: exactly one flow rate producer should be available for each circuit. Serially connected pumps are not a possibility. If three-way valves are used in places for which a flow direction is already defined, this results in an over-definition for the flow-rate. Below are some examples:

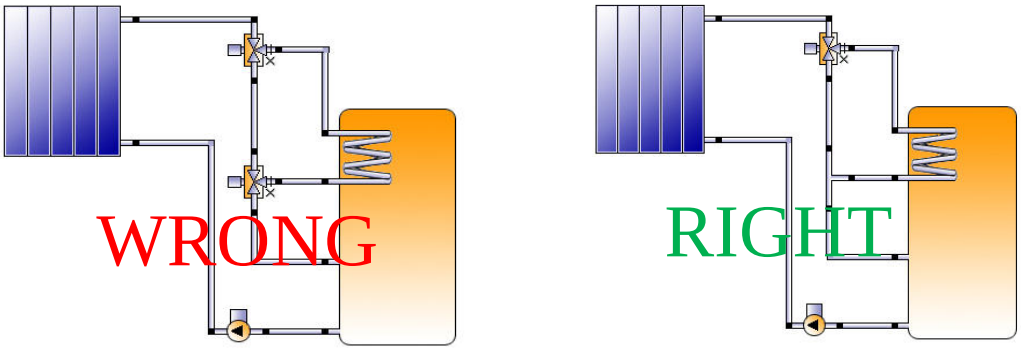


Figure 76: Three-way valve examples - the lower valve is unnecessary as the upper valve and the coil determine where the fluid should be flowing through

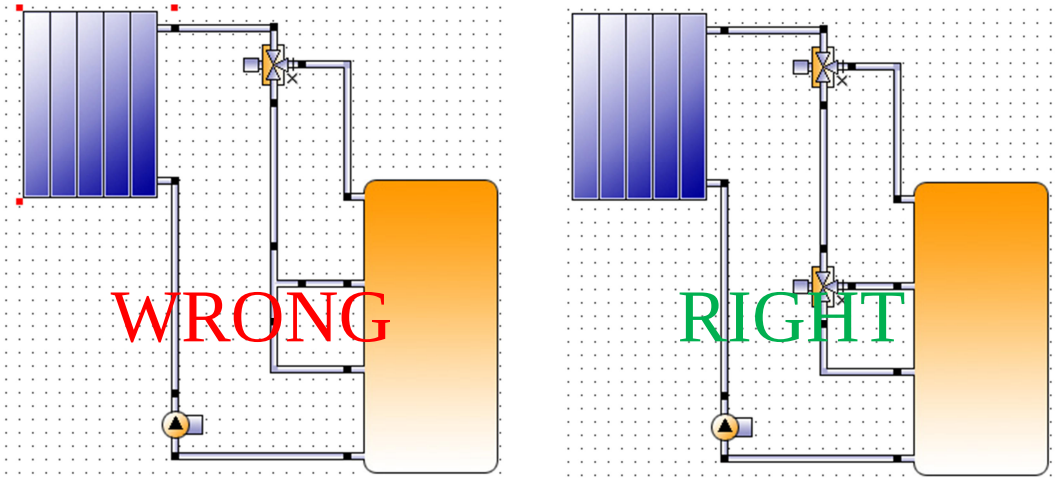


Figure 77: Three-way valve examples – Without a coil in the tank, the lower three-way valve is required to determine whether the fluid should flow out at the second port from the top.

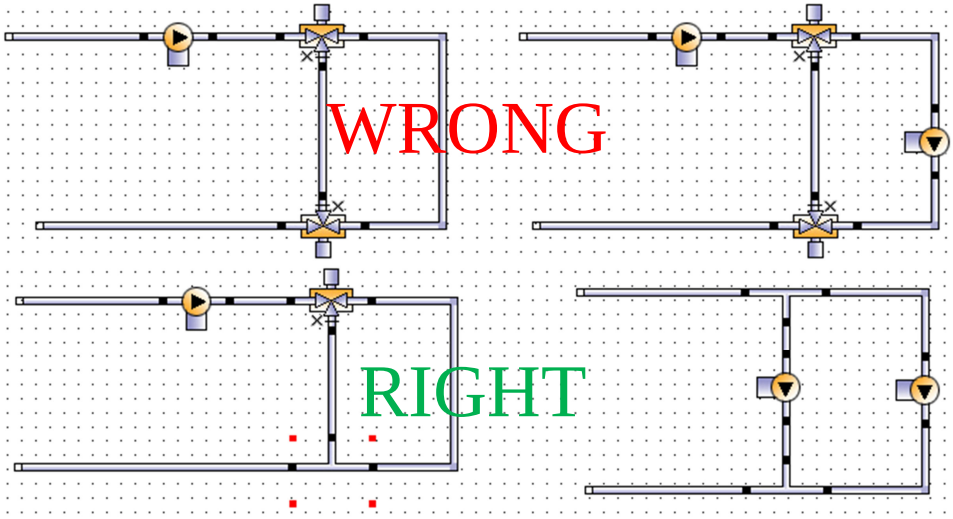


Figure 78: Three-way valve examples – In the examples above there are too many flow-determining elements

9.5 Labels

The properties of a component may be illustrated by adding a label to the drawing area. Furthermore, additional information that the user has regarding the component may be added to the label.
Another feature allows you to modify values directly through the label. In the Designer version the most important labels for a component can be generated automatically in just one click.
Select the label symbol from the tool bar and click on the component for which you want to add the labels.

10 References

[1] E. Vrettos and S. Papathanassiou, "Operating policy and optimal sizing of a high penetration RES-BESS system for small isolated grids," *IEEE Transactions on Energy Conversion*, vol. 26, no. 3, 2011.

[2] E. Vrettos, A. Witzig, R. Kurmann, S. Koch and G. Andersson, "Maximizing local PV utilization using," in *EU PVSEC*, Paris, 2013.